A SUMMARY OF

THE GEOLOGY OF INDIA

BY

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OF THE

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THIS WORK

IS DEDICATED TO

MR. R. D. OLDHAM

WHO INITIATED THE AUTHOR INTO THE

STUDY OF INDIAN GEOLOGY

ERRATA.

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INTRODUCTION.

Peninsular, extra-peninsular, and Indo-Gangetic regions.

FROM a geological point of view India is divided into three regions, (1) the peninsular area in which there are no mountains in the true sense newer than palæozoic, (2) the region of relatively recent mountains upheaved in tertiary times, constituting the ranges of the Himalaya, Baluchistan and Burma, and (3) the great Indo-Gangetic alluvial plain. These divisions are intimately connected with the physiographical history of the countries that now constitute the Indian Empire. In the Peninsula all the rocks of Upper Palæozoic age, or newer, are either horizontal, or dipping at comparatively low angles. The principal type of disturbance that has affected the peninsular area since the Upper Palæozoic is the formation of elongated almost rectilinear trough faults which are of paramount importance in the mineral resources of India, as they account for the formation and preservation of the Indian coal-basins. The central and western portion of the peninsular area is occupied by an enormous outcrop of heavy, black, volcanic rocks known as the Deccan Trap. It constitutes flat-topped hills, built of piled-up flows of basaltic lava, which have remained almost undisturbed since they were erupted in cretaceous times. The faulted troughs constituting the coal-basins occupy relatively small areas, principally in the eastern and north-eastern part of the peninsular region. Outside of these coal-basins the rocks constituting the peninsular area, wherever they are not concealed by the Deccan Trap, are mostly of palæozoic or older age, with the exception of a fringe of cretaceous and tertiary strata at some points along the sea coast. These coastal formations include the

only fossiliferous marine sediments of the peninsular area. The absence of such beds from the remainder of the peninsula indicates that this portion of India has been a continental area ever since the earliest geological times, and is one of the oldest land areas of the globe.

The rocks constituting the extra-peninsular area, that is, the mountain ranges of the Himalaya, of Baluchistan and of Burma, contain, in addition to a substratum of rocks identical with some of the older ones of the peninsula, numerous representatives of marine fossiliferous strata of almost every geological age from Cambrian to Tertiary. The area remained mostly occupied by the ocean until late in Tertiary times, when the upheaval of the Himalaya was completed.

The great Indo-Gangetic plain, which now connects the essentially different peninsular and extra-peninsular areas, consists of alluvial soil mostly derived from the disintegration of the Himalaya, whose rapid accumulation has finally obliterated all remnants of an arm of the sea which might still have subsisted between the two areas.

The following are amongst the most important geological formations represented in India:—

Newer river alluvium.

Recent and Pleistocene volcanoes.

Older river alluvium and raised beaches of Pleistocene age.

Siwalik System of Upper Miocene and Pliocene age.

Pegu or Mekran System (petroliferous series) of Oligocene and Miocene age.

Khirthar Series
Laki Series (Tertiary coal-measures)
Ranikot Series
} Eocene.

Deccan Trap, a volcanic formation of Upper Cretaceous age.

Marine and fluviatile representatives of the Upper Cretaceous.

Marine and fluvio-marine representatives of the Lower Cretaceous.

Marine
- Jurassic .. Upper } Gondwana (fluviatile).
- Trias .. Middle } Gondwana (fluviatile).
- Permian .. Lower } Gondwana (fluviatile).
- Carboniferous.
- Devonian.
- Silurian.
- Cambrian } Vindhyan.
- Precambrian } Vindhyan.

Kadapah System of Algonkian age.

Dharwar System of Huronian age.

Archæan gneisses and schists.

Each of these divisions includes several stages or substages.

Owing to the vastness of the area which has to be dealt with in a description of the geology of India, it often happens that one particular stage is represented by very differently constituted formations in regions separated by great distances.

The difference is especially marked between the peninsular and extra-peninsular regions which, as already mentioned, have had a very different geological history ever since Cambrian times.

Up to the Cambrian period the Peninsula or at least some parts of it, remained susceptible to orogenic influences, and considerable areas received marine sediments, mostly unfossiliferous, the analogues of which can be recognised in the extra-peninsular mountainous regions. After the Cambrian the peninsula remained a continental area and no longer received any marine sediments except along the coastal regions. Nevertheless, in some instances, fluviatile sediments were laid down in the centre of the Peninsula contemporaneously

with certain marine beds of the extra-peninsular mountains or the coastal regions. In consequence of such a difference of origin, the several contemporaneous formations, peninsular and extra-peninsular or coastal, differ widely in their characters and have been described under separate names. A great many local names have thus been established by Indian geologists, and, although as the regional surveys become linked together, many of them must become superfluous through synonymy, yet, in some cases, the regional character or "facies" is so special as to demand the retention of local names, especially when some doubt subsists as to the exact location of a particular formation within the standard geological time-scale of Europe.

Distribution of various types of rocks.

The contrast between the peninsular and extra-peninsular portions of India, is mainly due, therefore, to their essentially different character as representing two opposite types of the earth's crust. The extra-peninsular mountainous regions belong to the unstable and pliable portions of the earth's crust which are liable to be alternately depressed and raised above the surface of the ocean and thus become occupied by marine sediments, while the Peninsula belongs to the rigid or "continental" type, and has had its character of stability impressed upon it ever since Cambrian times, since when it has remained continuously a continental area. Consequently the interior of the Peninsula carries no marine formations later than Cambrian, and, even along the coast, the marine formations are discontinuous and of relatively small thickness, merely the stranded remnants left by those great marine invasions that recurred at several periods of the earth's history and are known as "transgressions."

The Peninsula an ancient continental region.

In the extra-peninsular mountains, in addition to an ancient substratum of rocks analogous to the oldest peninsular rocks, we observe an enormous thickness of marine strata embracing the entire series of the known geological formations from Silurian to Tertiary. As the floor of the " geosyncline " upon which they were laid down subsided simultaneously with sedimentation, the thickness of these formations bears no relation to the varying altitudes of the sea-level produced by the various geological transgressions and regressions.

Peninsular, coastal and extra-peninsular facies.

Owing to these initial differences, we often find therefore that formations of one and the same age are represented by three entirely different types: first, in the interior of the Peninsula by fluviatile beds which, for reasons that will be explained later, may attain a considerable thickness; second, by marine formations of relatively small thickness along the coastal regions of the Peninsula; third, by marine formations of vast thickness in the geosynclinal regions.

THE ARCHÆAN.

Definition.

THE Archæan, if one restricts this name to the rocks underlying the oldest undoubted sediments, consists essentially of crystalline gneissose rocks that must have solidified under conditions quite different from those that attended the formation of later rocks. These gneisses represent, in part at least, the original crust of the globe, when the surface of the originally molten mass first began to solidify.

Constitution.

As in other parts of the world, the Archæan system in India is largely made up of rocks whose composition and structure resemble those of the intrusive rocks of the family of the granites or diorites—granular aggregates of quartz, felspar (silicate of alumina and of alkali or lime), and various ferro-magnesian silicates, such as amphibole, mica of certain kinds, or less frequently pyroxene. These rocks differ from many of the true intrusive granites and diorites of later ages owing to the pronounced parallel arrangement of their constituting minerals, producing the structure known as gneissose. In addition to the parallel arrangement of the minerals within the rocks, the whole mass is often arranged in parallel layers of rapidly varying composition. In some of these rocks felspar is scarce or absent, and thus they pass from the condition of gneisses to that of crystalline schists. Amongst the most peculiar types of this class are the sillimanite schists of Orissa discovered by Dr. Walker and named by him "khondalites" (Memoirs of the Geological Survey of India, Vol. XXXIII); also the corundum bed of South Rewa, in Central India; the manganiferous garnet-bearing schists and gneisses discovered by Mr. L. L. Fermor,

and called by him the "kodurites." There are many outcrops of garnet-bearing mica schists.

It is possible, though by no means certain, that some of the schists, like the Khondalites and Kodurites, represent metamorphosed sediments. The chemical composition of the sillimanite-schists (Khondalites), and of certain mica-schists resembles that of clays, shales, and slates of sedimentary origin. In many instances mica-schists have been traced along the line of strike into connection with slates of recognisable sedimentary origin. For instance, it has been established in several parts of India that certain mica-schists of Archæan appearance often highly metamorphosed through their being permeated with granite intrusions, are metamorphosed representatives of the sedimentary Dharwars. In other instances no such connection has been established, and, in the case of the Khondalites, their close proximity to unmetamorphosed Dharwars indicates that if they represent transformed sediments, these are older than the Dharwars and had already been metamorphosed previously to the deposition of the Dharwar beds. It is convenient therefore at the present stage of the study of Indian geology, to group together all the pre-Dharwar rocks as Archæan.

Classification of the Indian Archæan.

A certain number of more or less definite types have been recognised amongst the Archæan rocks of India. The following types have been recognised over large areas :—

1. BUNDELKHAND GNEISS (Mallet, Manual of the Geology of India, p. 10, 1879), consisting of massive granitic gneisses.

2. NILGIRI GNEISS or MOUNTAIN GNEISS (King, Memoirs of the Geological Survey of India, Vol. XVI, p. 125, 1880), consisting of bedded dark-coloured gneisses usually of the composition of diorite, and generally containing garnets, characterised invariably

by the presence of the mineral hypersthene (normal silicate of magnesia, more or less ferriferous); also known as the CHARNOCKITE SERIES (Holland, Mem. G. S. I, Vol. XXVIII, p. 119, 1900).

3. BENGAL GNEISS (Oldham, Mem. G. S. I., Vol. I, 1859), consisting of banded and foliated gneisses, including mica-schists and other schistose rocks interleaved with granitic and dioritic gneisses; (this group is probably heterogeneous).

4. BEZWADA GNEISS (King, Mem. G. S. I., Vol. XVI, p. 205, 1880), consisting principally of banded quartzose schists or gneisses characterised by the abundance of the mineral sillimanite and the presence of graphite, also known as the KHONDALITE SERIES (Walker, Mem. G. S. I., Vol. XXXIII, part 3, p. 3, 1902).

The Bengal Gneiss.

The Bengal Gneiss is characterised by its varied composition and conspicuously banded structure. It often exhibits rapidly alternating layers of sharply contrasted composition, some of which exhibit the characters of gneissose granites and diorites, while others are more of the nature of schists. The schistose types are very numerous, including quartzose, micaceous and hornblendic schists, garnet-bearing schists and metamorphic limestones.

The Bengal Gneiss almost certainly includes a heterogeneous assemblage of rocks of various ages whose association constitutes nevertheless a peculiar type characterised by its extremely foliated constitution, which it is useful to keep separate in the present classification. Detailed studies of certain areas have enabled us to separate from it certain groups of rocks such as the Khondalites recognised by Dr. Walker and Mr. Middlemiss as identical with the Bezwada Gneiss of the East Coast, and it is probable that, with the further extension of the present researches, the Bengal

Gneiss will eventually be split up into several separate systems.

In addition to its banded or bedded structure that distinguishes it from the more massive Bundelkhand Gneiss, the Bengal Gneiss is characterised mineralogically by the frequency of rocks containing soda felspars (principally oligoclase), constituting therefore true diorites, while potash felspars largely predominate in the rocks of the Bundelkhand type which, petrologically, are true granites.

Bundelkhand Gneiss.

The Bundelkhand Gneiss, which, in its type area, usually has the appearance and composition of a coarse typical pink granite, was once regarded as the oldest rock in India. At a time when gneisses were regarded as metamorphosed sediments, the coarseness of crystallization was thought to be related to the degree of metamorphism, and consequently to the antiquity, of the rocks. As the oldest rocks of the earth's crust must include representatives of its first definitive consolidation from its original molten condition, it is evident that the Archæan must consist largely of rocks formed under conditions different from any with which we are acquainted in the present stage of the globe's history. The Bundelkhand Gneiss, when the nature and composition of the rock are considered, closely resembles an intrusive granite, but differs from undoubtedly genuine granitic intrusions owing to the enormous area which it occupies. When the Archæan rocks first consolidated, the primordial atmosphere contained in the state of vapour the totality of the water that now forms the ocean, the volatile chlorides, as well as a large proportion of the carbonic acid and oxygen that have now been absorbed by various solid rocks. It is quite conceivable that under the enormous pressure of this primordial atmosphere, molten masses may have spread out over large areas, and on solidifying assumed the

granitic form which at later periods could only have been developed under similar conditions of pressure and temperature in the depths of the earth's crust. Instead of being older than the Bengal Gneiss, it is quite possible therefore that the Bundelkhand Gneiss may be resting on a substratum of previously solidified rocks. Much of the banded structure of the Bengal Gneiss is due to the injection of molten rocks in the midst of previously solidified gneisses or schists. Some of these intrusions may be contemporaneous in age with the outflow of the Bundelkhand Gneiss. Thus, the Bundelkhand Gneiss, instead of being the oldest rock of the peninsula, may be newer than some parts at least of the Bengal Gneiss.

In the present state of our knowledge it is not possible to define exactly the chronological relations of these various types. Nevertheless, it is evident that they are amongst the oldest rocks of the globe—those constituting the series often spoken of as PRIMORDIAL or FUNDAMENTAL GNEISS.

Physiographical features of the Bengal Gneiss and Bundelkhand Gneiss.

Whenever the Bengal Gneiss is contiguous to an outcrop of some other geological series, the latter almost invariably contains rocks that resist weathering better than the gneiss itself, which consequently occupies the lower ground, the adjacent harder series standing out as hills. When the Bengal Gneiss, unaccompanied by any other geological formation, spreads over an extensive region, it is apt to constitute hills usually of irregular outline.

Where granitoid bands of appreciable width constitute part of the Bengal Gneiss, they weather into the characteristic groups of piled up blocks of huge dimensions known as "tors." The same mode of weathering affects the Bundelkhand Gneiss, and the analogous gneisses of the Deccan.

Distribution of the Archæan Gneisses.

Apart from the extensive regions in the Bombay Presidency, in Central India, and in Rajputana, where the Deccan Trap or the Vindhyans determine the shape of the land, the main features of the Indian Peninsula are mainly due to the distribution of the various forms of Archæan Gneiss.

The Nilgiri Gneiss and the Khondalites resist disintegration and erosion to a remarkable extent, and constitute all the highest mountains of the Peninsula, such as the Western Ghats from Coorg to Cape Comorin, the Ceylon mountains, the Palni, Anamalai, Shevaroy, and Nilgiri hills, and other great hill masses of Southern India, the tall range of hills constituting the continuation of the Eastern Ghats between the Godavari and Brahmani, probably also Parasnath hill in Bengal.

The massive granitic gneisses of the type of the Bundelkhand Gneiss usually occupy a plateau-like expanse intermediate in altitude between the lofty hills of Nilgiri Gneiss or Khondalite, and the low land occupied by the banded and schistose gneisses of the Bengal Gneiss type. It is especially as the main constituent of the great plateau of the Deccan that the massive granitic gneisses of the Bundelkhand type occupy a conspicuous position in determining the physiography of India.

In its type-area, the Bundelkhand Gneiss constitutes principally a plain, surrounded by cliffs of the much harder Vindhyan sandstones. This plain is traversed by great rectilinear, wall-like ribs of quartz constituted by huge veins of that substance many miles in length.

Quartz-Veins of Bundelkhand.

They give rise to rugged hills, imparting quite a special character to the scenery of Bundelkhand, and affording great facilities for the creation of artificial lakes.

Distribution of Bengal Gneiss and Bundelkhand Gneiss.

Lower Bundelkhand is the principal area of this form of gneiss in Northern India. The Bengal Gneiss occupies large surfaces in Behar, Manbhum, Orissa, Rewa. As regards Southern India the schistose gneisses that have been described as Karnatic Gneiss or Salem Gneiss, partly correspond with the facies of the Bengal Gneiss, while the facies of the Bundelkhand Gneiss recalls that of the massive granitoid red gneiss which prevails in the upland of Southern India and has been distinguished under various names such as Balaghat or Hosur Gneiss, or Bellary Gneiss. Its eastern confines from the Palar to the Kistna are almost continuous with the edge of the ghats, and it is typically developed in North Arcot, in the Kadapah sub-division, in the eastern part of the Bellary district, in the Karnul district, and thence all over the eastern portion of the Hyderabad Territory up to the higher reaches of the Godavari river. It has been largely used as a building material throughout Southern India. The magnificent buildings of Vijaynagar, in particular, are constructed of Hosur Gneiss.

Central Gneiss of Himalaya.

The Central Gneiss of the Himalaya is in part at least of Archæan age, but in the present state of the survey cannot always with certainty be distinguished from intrusive granites of various ages; neither are the available descriptions sufficient to tell whether the Bundelkhand Gneiss or Bengal Gneiss facies is more particularly represented. Rocks resembling the Nilgiri Gneiss have not been recorded Still more scanty is our knowledge regarding the Fundamental Gneiss in the Burmese and Malay region, though the system is there also represented.

The Nilgiri Gneiss.

Owing to the conspicuous part which it plays in the geology and physiography of Peninsular India, and owing also to

its remarkable petrological constitution, the Nilgiri Gneiss deserves special notice.

In the bulky hills which it constitutes, the rocks show a very distinct bedded disposition, the strata, which are sometimes very thick, varying in composition and in coarseness of grain. The great hill-masses constituted by this rock are often bounded by precipitous scarps leading up to extensive plateaux occupied by rolling downs, and often diversified with natural or artificial lakes The peculiar alteration-product known as laterite is extensively spread on these plateaux.

Petrologically the leading features of the rocks constituting the Nilgiri Gneiss are their dark colour and the constant presence of the mineral enstatite or hypersthene, (Fe Mg) SiO_8. They very frequently contain garnet which results from the interaction between the hypersthene and the adjacent felspar. The reaction is usually accompanied by the separation of a certain amount of free silica crystallizing as quartz forming micropegmatitic intergrowths with the garnet. Some varieties contain quartz as a primary constituent, others do not, but even when there is a high proportion of quartz, this mineral assumes a dark bluish colour, which does not affect the general dark tinge of the rock, producing a very different appearance from that of the more familiar types of quartz-bearing rocks, such as ordinary granites and diorites. The heavier and less siliceous types of the Nilgiri or Mountain Gneiss belong to the class of rocks known as " norites," while the more siliceous ones come nearer to the composition of diorites and granites, from which they differ nevertheless owing to the presence of enstatite, a mineral characteristic of rocks that have a low percentage of silica, but generally absent from the usual types of highly siliceous rocks, such as normal granites or diorites. Amongst these enstatite-bearing rocks, the types that most nearly approach a granite in compo-

sition have been called by Sir Thomas Holland "charnockites," because the tombstone of Job Charnock, the founder of Calcutta, consists of a slab of that rock:[1] the material is much appreciated as an ornamental stone, owing to its handsome granular appearance and dark colour.

Charnockite.

The famous sculptures and rock-cut temples of the "Seven Pagodas" near Chingleput, south of Madras, are carved out of a somewhat abnormal form of the Nilgiri Gneiss. Various forms of Nilgiri Gneiss have supplied the materials for the gorgeous Hindu temples of Chidambaram, Tanjore, Trichinopoli, and Madura in Southern India, and the wonderful ancient Buddhist buildings of Anaradhapura in Ceylon.

The Khondalites (Bezwada Gneiss) which consist essentially of quartz, sillimanite and graphite, are very peculiar rocks. Consisting as they do of the most unalterable of minerals, they withstand weathering to a remarkable degree and contribute with the Nilgiri Gneiss to form the rim that borders the peninsula in Vizagapatam and Orissa, between the Godavari and Mahanadi.

Bezwada Gneiss or "Khondalite."

In the field the Khondalites have the appearance of excessively massive quartzites, weathering to a dark buff colour occasionally stained with brown spots caused by the superficial decomposition of small garnets. The famous rock-cut Buddhist "Vihara" of Undavilli near Bezwada on the Lower Kistna is carved out of a hill of "Khondalite."

[1] The name "Charnockite Series" has been used by Sir Thomas Holland to designate all the rocks of the Nilgiri Gneiss. When using the term in this sense, it should be remembered that Charnockite proper, that is hypersthene-granite, constitutes only an exceptional member of a series, the bulk of which is made up of rocks approximating in composition to a quartz-diorite. By means of the name "Nilgiri Gneiss," it is possible to avoid the confusion liable to occur from using the word "Charnockite" in two different senses.

In some parts of Southern India, rocks regarded as identical with the Nilgiri Gneiss are said to be intruded amongst folded and metamorphosed sedimentary beds corresponding with the Dharwar Series. The latter identification owing to the degree of metamorphism is open to question, and the rocks may be schistose representatives of the Bengal Gneiss. Moreover, even if the folded beds were unquestionably of Dharwar age, this would not suffice to prove that the apparently intrusive rocks is newer. In the deepest portions of these ancient folds, solid rocks seem to have recovered a certain amount of fluidity and to have reacted upon one another, simulating the effects of contact metamorphism, although there may not have been any real intrusion. In Southern India, where the Hosur Gneiss, the local representative of the Bundelkhand Gneiss, comes into contact with the Nilgiri Gneiss, there is some evidence pointing to their being both of about the same age, while we have the direct evidence of stratigraphical superposition to prove that the Dharwars, the local representatives of the oldest sedimentary system, are newer than the Hosur Gneiss.

Stratigraphical relations of the Nilgiri Gneiss and Dharwars.

Thus, there is every reason to regard the Nilgiri Gneiss as a member of the Archæan System, either of the same age as the Bundelkhand Gneiss, or somewhat newer.

A remarkable rock which has been regarded as related to the Nilgiri Gneiss is the "anorthosite" occurring south of the Raniganj coal-field in Bengal. It is remarkable for the large proportion of the lime alumina silicate anorthite which enters into its composition

"Anorthosite."

THE DHARWAR OR HURONIAN.

After the consolidation of the original crust of the globe now constituting the Archæan rocks, a time must have come when the temperature was sufficiently lowered for the vapours contained in the primordial atmosphere to condense and form the ocean. Subsequently to this event, the temperature of the earth's crust could no longer vary except within narrow limits, while the temperature of the inner core of the globe continued slowly to decrease, and is still decreasing at the present day. In order to adjust itself to the contraction in volume which results from this gradual cooling of the earth's interior, the outer crust became corrugated into ridges and furrows. The inequalities thus arising in the earth's figures became gradually more pronounced, and at last some of the troughs absorbed so much of the bulk of the waters, that the general level of the ocean surface sank below that of the highest ridges or bulges. In this manner the first continents appeared, and as their surface became at once degraded by atmospheric agencies, true sediments began to accumulate in the neighbouring parts of the ocean. The gradual deepening of the ocean, and the consequent expansion of the continents, by raising these earliest sediments above the sea-level, accounts for their rapid removal by denuding agencies. Consequently they have now almost everywhere disappeared, except where portions of them have been caught up amidst the folds of subsequent corrugations, such as those which accompany the formation of mountain ranges. The increased depth and thickness resulting from this compression has saved some of these folded portions from being completely removed by denuda-

Characters of oldest sediments.

tion. This is why the oldest sediments of the globe are almost entirely restricted to narrow highly compressed synclines. Consequently their outcrops assume the appearance of more or less parallel narrow elongated strips, such as is particularly well shown in the Dharwar region of Southern India. It is the deepest parts of the original synclines that are thus preserved, precisely those parts where the combined effects of compression and heat have produced the most intense degree of metamorphism, and as this is often enhanced by the contact effects of igneous intrusions, a crystalline facies may be produced, which it is sometimes very difficult to distinguish from that of certain forms of Archæan gneisses.

Constitution of the Dharwars

Amongst the most characteristic rocks of the Dharwars may be mentioned: hæmatite-schists, magnetite-bearing schists and massive beds of hæmatite and magnetite; massive beds of manganese ore; a great variety of more or less altered volcanic beds, principally felsites or rhyolites and basic rocks which were original basaltic or dolerític, but which have mostly been converted into epidiorites; hornblendic schists which probably represent metamorphosed volcanic ash-beds, various kinds of highly magnesian rocks, such as talc-schists, serpentinous limestones, potstones; carbonaceous shales or slates; boulder beds; highly crystalline limestones and dolomites passing sometimes into scapolite-gneisses and pyroxene granulites, which appear to be the result of metamorphism from associated granitic intrusions.

Single outcrops of this ancient sedimentary series, as a rule, do not contain everyone of these forms of rocks. for instance, the crystalline limestones so conspicuous in the Jabalpur and Aravalli outcrops are almost absent from the Dharwars of Southern India; but the different types of rock are always associated

in sufficient variety to lend to the formation its characteristic facies The bulk of the formation usually consists of a considerable thickness of slates showing every passage from indurated shales through chiastolite-bearing slates and semi-crystalline phyllites to typical mica-schists often with the development of staurolite, andalusite and garnets. When the slates are but slightly altered, they are not readily distinguishable from those of some less ancient series of the Peninsula, the Kadapah system for instance ; but they frequently exhibit the altered schistose facies over large areas with a degree of metamorphism which is only observed quite locally, if at all, amongst the rocks of Kadapah age.

Granitic intrusions varying in size from large bosses to narrow veins are a frequent feature amongst the outcrops of these the oldest sediments. Some of the finely foliated mica-schists are, as it were, impregnated with narrow strings of intrusive granitic material, the combination thus produced giving readily the impression of a gneiss.

Such instances, as also those of the highly crystalline scapolite-gneisses and pyroxene granulites resulting probably from the combined influences of dynamic and contact metamorphism, as also the existence of large outcrops of highly crystalline mica-schists are amongst the circumstances that tend to produce confusion between genuine Archæans and altered sediments. Instances have been observed, however, where a direct connection can be traced between outcrops of highly metamorphosed rocks and others in which the alteration is of a much slighter degree. Of particular interest in this respect is the belt that extends east-west from the neighbourhood of Midnapore to that of Nagpur. In the eastern part of the outcrop, in Chota-Nagpur, the southern part of

Metamorphism of Dharwars

the Dharwar belt consists of unmetamorphosed slates, sandstones and limestones, dipping at low angles and spreading over a broad area, while along the northern margin of the belt in this same district the degree of alteration is much more pronounced. Further west, in Gangpur State, this altered facies affects even certain associated rocks of Kadapah age, while still further west, towards Raigarh and Balaghat, the outcrops assume the usual narrow synclinal structure, and the slates are gradually replaced by phyllites in Balaghat district, and by schists and gneisses in Nagpur district.

Amongst the various rocks of the system, the massive beds of manganese ore and the still more massive iron ores are particularly characteristic. Similar rocks occur in some of the divisions of the succeeding Kadapah, but never in such bulky masses. The brilliantly coloured banded jaspers are amongst the most conspicuous rocks of the oldest sediments, but they are equally well developed in the succeeding Kadapah.

Banded jasper.

The iron ores of the Dharwars are often inter-banded with granular quartz, constituting a rock known as hæmatite-quartzite. This rock generally withstands disintegration better than other members of the Dharwar series and consequently it usually constitutes ridges. When the rock is unaltered or only slightly altered, the iron ore consists principally of hæmatite; when it is much affected by pressure metamorphism, there is a large proportion of magnetite. The iron ore and quartz are often accompanied by mica and by the iron silicate known as grunerite $(FeO{\cdot}SiO)_2$, a mineral related to the class of the amphiboles.

Iron-ores of Dharwars.

In many instances the banded iron ores are obscurely associated with basic volcanic rocks. A very frequent rock in regions where the Dharwars have

been much metamorphosed is a mica-schist or phyllite crowded with crystals of magnetite or martite.

Some of the Dharwar sandstones are very felspathic and are somewhat of the nature of an arkose. Sometimes the felspar after being removed by weathering, leaves an aggregate of interlocking quartz grains held together owing to secondary growths of the quartz, though the particles are capable of a certain amount of relative displacement: this material constitutes the curious "flexible sandstone" which is quarried at Kaliana, near Dadri, in Jind, amongst the northern spurs of the Aravalli range.

Flexible sandstone.

One is tempted to ascribe the prevalence of felspathic sandstone to the fact that at the early period of the globe's history during which these beds were deposited, the sedimentary materials had not been sorted out by repeated cycles of denudation to the same extent as in later times. for instance, the sandstones of the Mesozoic or Tertiary often represent the redeposited detritus from a pre-existing sandstone; the shales of these latter ages are often the redeposited material from a pre-existing shale; while at the time of the deposition of the Dharwars, the sedimentary rocks were derived directly from the disintegration of undifferentiated plutonic rocks. Yet there is another agency, by which the presence of undecomposed felspar in a sandstone can be accounted for, that is, the cold temperature that accompanies a glacial period when the silicate grains are set free by disintegration of the rocks without undergoing decomposition. The existence of glacial conditions at this early period of the globe's history when one would expect that the earth's crust and the ocean might still have been affected by the internal heat, seems rather a paradox, and is scarcely in keeping with the occur-

rence of such rocks as the banded jaspers which suggest a warm ocean; yet this supposition receives a curious support from the presence of the remarkable boulder beds which occur at certain horizons of the Dharwar, and which, owing to the presence of large boulders scattered through a fine silty matrix, bear an extraordinary resemblance to typical glacial formations.

Glacial beds of Huronian age

The pebbles in the Dharwar boulder beds consist largely of rocks derived from the Dharwars themselves. This shows that the older members of the Dharwars had already been upheaved and were undergoing denudation before the close of the Dharwar period, and that, in spite of its homogeneous appearance, the Dharwar System really includes several uncomformable divisions. It has not been possible, so far, to make out any definite succession otherwise than quite locally: the overfolded condition of the synclines renders it difficult to detect the true order of the strata, and the synclines are often incomplete on one side owing to overthrusts.

The presence of pebbles of the volcanic felsites and rhyolites in the conglomerates of the Gadag synclinal band of the Deccan observed by Maclaren is interesting as showing that those acid volcanic rocks belong, partly at least, to the older stages of the Dharwars. It is probable that some of the intrusive granites penetrating the Dharwars are the hypogene (deep-seated) representative of these acid volcanics.

At the time when the Dharwars were deposited, the areas which they now occupy behaved after the manner of geosynclines: that is, the floor of the ocean subsided simultaneously with the accumulation of the sediments; consequently, as is usual in a geosynclinal area, the system

Geosynclinal character of Dharwar outcrops.

attains a vast thickness, which in many instances cannot be less than 20,000 feet.

Intrusive granites and pegmatites.

Amongst the rocks that are intrusive in these ancient Aravalli or Dharwar beds, yet undoubtedly older than the overlying Kadapahs, may be mentioned granites, which are of medium grain when the intrusion assumes the shape of a compact boss, as in the case of rock known as "dome-gneiss" in Hazaribagh, or the Erinpura granite in Rajputana, but which become extremely coarse-grained pegmatites when the shape of the intrusion becomes that of a comparatively narrow dyke. When the pegmatites traverse mica-schists, they usually contain marketable mica, as in the pegmatite veins of Rajputana, Hazaribagh and Nellore.

Elæolite-Syenites.

Another group of intrusions, probably of the same age, consists of some very interesting rocks containing minerals of the group of the felspathoids, such as the elæolite-syenites of Sivamalai hill in Coimbatore (Holland, Mem. G. S. I., Vol. XXX, p. 169), of the Vizagapatam hill-tracts (Middlemiss, General Report, G. S. I., 1902-03, p. 25), and the elæolite-sodalite-syenites of Kishengarh in the Aravalli range (Vredenburg, Rec. G. S. I., Vol. XXXI, p. 43)

Tourmaline-granites.

Petrologically the intrusive granites of Dharwar age often resemble closely some of the Archæan granitic gneisses from which they can usually be distinguished owing to the abundance of the mineral tourmaline.

Rare minerals in pegmatites.

The quartz-pegmatites and elæolite-syenite pegmatites often contain minerals of interest to science or of value to industry. Amongst those found in the elæolite-syenite-pegmatites, are cancrinite molybdenite, ægerine. The quartz-mica pegmatites

have yielded large crystals of beryl sometimes of value as gems, gadolinite, columbite, allanite, pitchblende, torbernite, triplite, tinstone.

Many of the remarkable minerals occurring in the extreme south of the peninsula and in Ceylon are probably derived from intrusive rocks of this same period.

Of the same age are perhaps the "dunites" (rocks rich in chrome and magnesia) of the Salem district and other parts of Southern India.

Distribution of the Dharwars.

South of latitude 11° there do not appear to be any outcrops of Dharwars. The formation seems absent also from a considerable portion of the Deccan plateau in the Nizam's Dominions especially between Hyderabad and the upper reaches of the Godavari. It is also absent from the hilly region of Vizagapatam and Orissa which runs parallel with the coast between the Godavari and Mahanadi, and also from the Bundelkhand Gneiss area of Central India.

Peninsular representatives of the Dharwars.

Elsewhere the Dharwars appear in more or less connected outcrops wherever the Archæan rocks are exposed. In Peninsular India, the principal groups of exposure are those of the southern part of the Deccan (especially in the districts of Dharwar and Bellary, parts of the Nizam's Dominions, and the greater portion of Mysore); the Nellore portion of the Carnatic; Chota-Nagpur; the Balaghat and Nagpur regions of the Central Provinces; the Jabalpur region; Behar, Hazaribagh and Rewah; the Aravalli range; the Shillong region

Various names were applied to the different exposures in the earlier stages of the geological examination of India, such as Aravalli series in the range of that name; Champaner series in the southern prolongation of the range in Gujarat; Chilpi series in the Central

Provinces ; Shillong series in the Assam plateau ; Dharwar series in the Deccan. Since the recognition of the identity of the rocks constituting these various exposures it has become usual to apply to them all the name of Dharwar, first proposed by Mr. Foote.

Himalayan representatives of the Dharwars.

In the Himalaya the Dharwars are well developed both to the north and south of the crystalline axis of Archæan and granitic rocks. Along the northern border of the crystalline axis they constitute the Vaikrita series which underlies the Cambrian Haimantas ; their characters along this northern zone are greatly obscured owing to the effects of metamorphism which their position beneath thousands of feet of overlying strata previously to the Himalayan upheaval and the compression developed during the upheaval itself have superimposed upon their previously acquired metamorphism. South of the crystalline axis, there is no difficulty in recognising the various Peninsular formations by means of their petrological characters. The equivalents of the Dharwar system occupy an almost continuous band along the southern zone of the Himalaya where they have been described under various local names, such as the Simla slates and Jaunsar series in the Simla neighbourhood, or the Daling series in the Darjiling district. They include most of the rocks characterising the series in the Peninsula, and are frequently overlaid by the equivalents of the Peninsular Vindhyans.

The Miju ranges at the head of the Assam valley consist of these same rocks which are no doubt continued along the crystalline axis of Burma where they have not yet been clearly distinguished from the Archæan gneisses and schists.

Mineral richness of the Dharwars.

The Dharwars are of great economic importance as they yield the bulk of the metalliferous ores of India. They con-

stitute the chief auriferous series, and most of the ores of iron, manganese, and copper occur in connection with them.

Gold.

The Dharwar gold occurs either in quartz veins or as alluvial gold derived from the disintegration of the auriferous veins. The deposition of gold in the veins bears some obscure relation to the carbonaceous matter widely distributed in the Dharwar shales or slates, and to hydrothermal agencies that accompanied the various periods of volcanic activity indicated by the presence of neighbouring volcanic outflows or intrusive dykes.

The quartz veins are of two kinds, and consist either of dark-coloured "blue-quartz," or of white quartz. The veins of blue quartz already existed previous to the final compression of the Dharwars, and therefore show signs of crushing and crumpling. The white quartz veins appear to be nearly or quite undisturbed and must be therefore of post-Dharwar age.

It is evident therefore that the gold which occurs in connection with the Dharwar outcrops is not all of one age, and, as suggested by Maclaren, the gold in the blue quartz was probably deposited in connection with volcanic phenomena of the Dharwar period of volcanic activity, while that in the white quartz is probably connected with the Kadapah volcanics.

THE KADAPAH SYSTEM, OR ALGONKIAN.

THE orogenic effort that folded the Dharwars, has powerfully affected the Indian Peninsula. Later efforts of the same kind have been comparatively feeble, the latest of these not being later than the Older Palæozoic era.

The peninsular rocks that have been affected by orogenic movements in post-Dharwar times belong to two successive systems known as the Kadapah and Vindhyan, whose geological age roughly corresponds respectively with the Algonkian and Cambrian. The orogenic effort that has affected them acted intermittingly, for, when the Kadapah and Vindhyans occur together, one observes that the older system has been more violently contorted than the newer one. Moreover, both the Kadapahs and Vindhyans are divisible into several stages, the older of which are generally distinctly more disturbed than the later ones. Orogenic phenomena must therefore have affected the peninsula from time to time throughout the period of deposition of the Kadapahs and Vindhyans.

Post-Dharwar orogenic disturbance in the Peninsula.

The zones of weakness of the peninsula that yielded to compression in Vindhyan and Kadapah time are very narrow as compared to the vast areas over which the rocks were contorted in the preceding Dharwar era.

In Kadapah and Vindhyan times, the greater part of the Peninsula had already acquired the character of stability and rigidity which it has maintained through-

out all succeeding periods. the mountains of Kadapah and Vindhyan age were upheaved along certain zones where the earth's crust still preserved a residue of the flexibility that had characterised much larger portions of the peninsular area in Dharwar times. As a consequence of these structural differences, it follows that, while, on the one hand, in the case of the Dharwars, broad low-dipping outcrops are very exceptional, the rocks generally appearing as narrow compressed synclines, on the other hand, in the case of the Kadapahs and Vindhyans, the rocks usually spread with low angles of dip over considerable areas, and only appear highly tilted and contorted along a few zones of special disturbance.

Degree of disturbance of Kadapah and Vindhyan rocks.

The commonest type of outcrop observed amongst the Kadapahs and Vindhyans is that of a broad crescent-shaped expanse along the convex side of which the strata dip gently away from the underlying gneiss, while along the concave margin the rocks are tilted at high angles and contorted, and often exhibit overfolds and reversed faults indicating a thrust directed from the concave towards the convex side. The broad expanse of low-dipping rocks occupies the rigid portion of the crust that has stood as an obstacle to the orogenic compression, and, as in the case of mountain systems of later age, the convexity of the mountain border is turned towards the rigid obstacle. Both the convex and concave sides, the latter especially, coincide to a certain extent with original limits of deposition, and one frequently notices that the rocks increase in coarseness and that sandstones and pebble beds become more prevalent on approaching their borders, especially the concave one.

Characters of Kadapah and Vindhyan outcrops.

The zone adjacent to the concave side of the great crescent-shaped outcrops above mentioned represents

a region of special elevation, and was once occupied by the mountain ranges whose disintegration supplied the materials that accumulated to form the Kadapah and Vindhyan sediments. It is only from the geological peculiarities of their structure that these zones can be recognised as former mountain ranges. The long ages of continued subaerial denudation that have affected the Peninsula since early palæozoic times have reduced these ancient mountains to the same average level as the surrounding country.

The present topography is entirely determined by differences of hardness between the various strata, the massive sandstones standing out as scarped ridges, the softer shales occupying the intervening valleys. The sandstone escarpments are often quite as lofty where the beds dip at low angles along the convex border of the great crescent-shaped outcrops as along the opposite concave border where, in former times, there stood great mountain ranges.

Type-area of the Kadapah rocks: the Vellikonda hills.

The most typical of the Kadapah outcrops is that from which the system derives its name, part of it occupying the district of Kadapah in the eastern part of the Deccan. The highly compressed rocks of the easten concave border constitute the Vellikonda hills which form a part of the Eastern Ghats A very similarly disposed outcrop occupies the plain of Chhatisgarh in the Central Provinces. The eastern border of the Aravalli ranges shows admirably the curved shape of these ancient mountain ranges. Only, while in the Kadapah and Chhatisgarh regions the thrust is mainly directed from east to west, in the Aravalli region it has acted in the opposite direction, and a vast expanse of almost horizontal strata, partly Kadapah, but mostly

Kadapah rocks of Chhatisgarh.

Vindhyan, lies east of the zone of overthrusts affecting the Vindhyans, that fringes the Aravallis.

Kadapah rocks of the Son-Narbada valley.

A similar disposition is observed along the valleys of the Son and Narbada south of the escarpment constituting the geographical feature known as the Vindhyan range. In this case the direction of thrust is between north and north-east.

It is worthy of notice that the zones of disturbance which, in Kadapah and Vindhyan times, must have been regions of special upheaval, in several instances coincide with the zones of depression along which the crust of the earth subsided at a subsequent period between the trough faults that allowed the accumulation of the Gondwanas. It seems as though the degree of compression had "overshot the mark," and had to be compensated by a subsequent relaxation.

The bulk of the Kadapah system consists of shales and limestones. Slaty cleavage, varying in degree, is often observed in the shales, but the limestones never acquire the crystalline texture that is so common in the Aravalli system. As might be expected, the Kadapahs are intermediate between the older Aravallis or Dharwars and the newer Vindhyans, not only in point of the degree of alteration, but also in the nature of the rocks constituting the two groups. The shales which are often calcareous, and the somewhat thin-bedded limestones are essentially similar to those of the Vindhyan formation, but the Kadapahs also contain some of the characteristic Huronian rocks, such as the manganese and iron ores, and the banded jaspers. It is only the latter, however, that are equally well represented in both formations. These bright-red jaspers have been extensively used in the inlaid decoration of the buildings of Delhi and Agra.

There are two main divisions of the Kadapah, each consisting of several series separated from one another

by unconformities. The rocks resembling some of the Huronian beds, such as the banded jaspers, are specially abundant in the Lower Kadapahs, while the Upper Kadapahs are more like the Vindhyans.

Of the two sub-divisions of the Lower Kadapah, the lowermost known as the Papaghni Series has been observed only in the type area of the Kadapah system in Southern India. The upper member of the lower Kadapah, known as the Bijawar Series, is widely distributed throughout India, and is easily recognized on account of its association with a grand volcanic outburst, the products of which consist of basic lavas, sills and ash-beds intercalated amidst the Bijawar sediments, and intrusive dykes and bosses of the same composition penetrating through rocks of greater age than the Bijawars. These dykes are interesting as being probably the original home of the Indian diamonds, now found as derived pebbles in the later Vindhyan conglomerates.

Volcanic rocks of Bijawar Series.

The commonest types of rocks of the Bijawar volcanics are augite-basalts with or without olivine. The less basic types without olivine often contain a remarkably large amount of micrographic quartz which is of such frequent occurrence in localities far distant from one another that it must be regarded as a primary constituent (Holland, Rec. G. S. I., Vol. XXX, p. 16). When these rocks have been subjected to intense pressure, they have been transformed into epidiorites (Vredenburg, Mem. G. S. I., Vol. XXXI, p. 70).

The Bijawars were first described in the State of that name in Bundelkhand (Medlicott, 1860), and were subsequently identified south of the Son River in Rewa, and north of the Narbada River in Dhar Forest. In the type-area of the Kadapahs, where their identity with the Bijawar Series was not at first recognized,

they were described under the name of Cheyair, and near Gwalior they were called the Gwalior Series.

The Penganga beds of the Pránhitá Valley also appear to belong to this same horizon.

The Bijawar, owing to its characteristic combination of volcanic rocks and banded jaspers, is the only stage of the Kadapah that can readily be identified from one place to another in the present state of geological investigation. When this stage is missing or is not typically developed, it becomes very difficult to establish any reliable order of succession in the Kadapahs.

Upper Kadapah.

The Upper Kadapahs are represented in the type-area of the Kadapahs by the Nallamalai and Kistna Series. The Kaladgi beds between Belgaum and Kaladgi are perhaps also of Upper Kadapah age.

In the Himalayan region there occur certain rocks somewhat resembling the Kadapahs, but the characteristic banded jaspers have not been met with, and, whilst the occurrence of the post-Kadapah system known as the Vindhyan can be established almost from end to end of the Himalaya, it is not possible to point out any undoubted representatives of the Kadapah.

THE VINDHYAN SYSTEM AND THE CAMBRIAN.

Sandstone facies and shaly facies.

THE Vindhyan System named after the Central Indian highland that extends north of the Narbada, Son, and Damuda, and south of the Jumna and Ganges, is a vast formation presenting two principal facies, one mainly characterized by limestones and calcareous shales, the other by enormously massive sandstone. As a rule, the Vindhyan strata dip at low or very low angles, and are even less disturbed than the Kadapahs Yet, along the south-eastern border of the Aravalli range, and in those places where the Kadapahs themselves have been conspicuously disturbed, the Vindhyans have also been affected by folding and overthrust, indicating that they too have shared in the mountain-forming disturbance. Even in such localities they are not affected to the same degree as the Kadapahs, and it is evident that the main phase in the disturbance of the Kadapah had been completed before the deposition of the Vindhyans, and that the Kadapahs had been greatly denuded in the interval.

Degree of disturbances of the Vindhyans in the Peninsula.

The Vindhyans in their type-area.

In their type-area, which covers an immense territory from Dehri-on-Son to Hoshangabad and to Gwalior, and from there to Agra and to Neemuch, the Vindhyans consist of four main divisions: a lower division exhibiting the calcareous facies which is known as the Lower Vindhyans; an overlying division consisting of two enormously massive sandstones known under the names of Kaimur and Rewa, separated by some subordinate shales; another division

mainly calcareous and similar to the Lower Vindhyans which is known as the lower Bhanders, and lastly, an uppermost division of massive sandstones known as the Upper Bhander. The calcareous divisions average some 1,500 feet in thickness each, the sandstone ones about 500

The Vindhyan shales are frequently carbonaceous. Conglomerates occur at various horizons within the Vindhyans; the most constant is situated at the base of the Kaimur sub-stage and often overlaps the Lower Vindhyans which, in some instances, had already to some extent been tilted and corrugated before the deposition of the Upper Vindhyans. In the Himalayan region the presence of conglomerates of Vindhyan age has given rise to a certain amount of confusion owing to their having been mistaken for the Talchir boulder bed of Gondwana age, and perhaps for other similar beds belonging to the Dharwars.

Kaimur conglomerate.

A remarkable group of highly siliceous volcanic rocks varying from rhyolites to quartz-andesites occurs in the Lower Vindhyans. Some of the limestones both in the Lower Vindhyans and in the Lower Bhanders exhibit a curious concretionary structure of spherules one to three centimetres, in diameter, consisting of variously coloured concentric shells in a matrix of a different colour. When the tints are vivid as in the case of the Sabalgarh stone near Gwalior, a strikingly beautiful material is produced which deserves to be more widely known. It has been largely used in the inlaid decoration of the buildings at Agra. Amidst the pebbles of certain Vindhyan conglomerates in Bundelkhand and in Southern India, there occur diamonds (the Panna and the Golconda diamonds) probably derived from the denudation of the basic volcanic dykes of Bijawar age.

Sabalgarh limestone.

There are several other outcrops besides that of the type-area of Central India, though none of them are so extensive. The Lower Vindhyans together with the Kaimur-Rewa sandstones are well represented in the Dhar forest (Nimanpur district) north of the Narbada, and in Western Rajputana, the latter exposure exhibiting a particularly fine development of the volcanic beds of the Lower Vindhyans, locally known as the Malani beds from the State of that name.

Vindhyan volcanics and granites of Western Rajputana.

In connection with the Malani rhyolites, there occur, in Western Rajputana, granitic bosses representing the hypogene (deep-seated) portions of the volcanic eruptions. They have been classified by La Touche as JALOR GRANITE, a rock containing both hornblende and biotite-mica, and SIWANA GRANITE, which contains hornblende but no mica.

Other outcrops of Vindhyan age.

All the other Vindhyan outcrops of the peninsula consist mostly or entirely of Lower Vindhyans. They constitute the "Karnul Series" of the district of that name and of the Bhima Valley. The Sullavai sandstones of the Godavari Valley perhaps belong also to the same formation, unless they represent the sandstone and shale formation known collectively as the Red Shale Series in Rewa, where it underlies the Lower Vindhyans, and might almost be regarded as an oldest member of the Vindhyan System. Amongst the mountains of Northern India, the Vindhyans are represented by the Deoban Series near Chakrata, the Krol Series and Infra-Krol of the Simla area, the Haimanta of the Northern Himalaya, the Attock Series of the Punjab, and a portion of the Panjal System in Kashmir.

Of these extra-peninsular occurrences, the Attock Series corresponds more particularly with the Lower

Vindhyans, the Krol Series more particularly with the Upper Vindhyans. The Haimanta probably includes both. Lithologically, the Himalayan representatives of the Vindhyans are distinguished from the peninsular rocks owing to a greater development of the limestones and shales and a more subordinate proportion of sandstone.

Building materials.

The Vindhyan limestones constitute a valuable source of lime, while the sandstones have yielded the material for the masterpieces of Indian art from the time of Ashoka to the present day. Amongst the buildings of Vindhyan sandstone may be mentioned the Buddhist stupas of Barhut, Sánchi, and Sarnáth, the exquisite temples of Kajraha, the palaces of Gwalior, Delhi, Agra, Fatehpur-Sikri, Amber, Dig, the magnificent Jumma Masjids of Delhi, Agra, and Lahore. According to which beds are selected, it is possible to obtain monoliths of Egyptian magnitude, or flags of the thinness of slates. Such a variety of excellent material is obtainable that, in certain parts of India, public buildings and private dwellings, from the flooring to the walls and to the rafters and ceilings are built entirely of stone. Large quantities of railing posts are manufactured out of Vindhyan sandstone, and, until a few years ago, it was the usual material for telegraph posts.

Vindhyan fossils.

In addition to tracts of animals of uncertain zoological affinity discovered by La Touche in Rajputana (Rec., G. S. I., Vol. XXXV, p. 248) the only distinct fossils as yet observed in the Vindhyans of the Indian Peninsula are certain small chitinous discinoid discs discovered by Mr. H. C. Jones in the neighbourhood of Neemuch in Central India in shaley beds which appear to belong to the Lower Bhander stage. They resemble certain Cambrian fossils from America and from Scandinavia.

Cambrian of the Salt Range.

In the Salt Range, the lowest formation exposed consists of a series of Cambrian sandstones, shales and limestones, whose lithology agrees so exactly with that of the Vindhyans as to leave scarcely room for doubt as to their identity Just as in the case of the Peninsula, the Cambrian of the Salt Range is directly succeeded by strata of Upper Carboniferous or Permian age, and the intervening members of the Palæozoic are absent.

The system is well developed in the eastern portion of the Salt Range, where its principal members are a purple sandstone, an arenaceous dolomite, and a group of bright-coloured shales with casts of salt crystals. The lower member, the Purple Sandstone, and the uppermost shales are quite unfossiliferous, but numerous fossils have been found in a band of shales intervening between the Purple Sandstone and the arenaceous dolomite. Lithologically the Purple Sandstone agrees with the Kaimur or Rewa sandstone, while the remaining beds appear to represent the Lower Bhander, the same beds therefore that have yielded fossils near Neemuch. The Salt-Range fossils are of Middle Cambrian age, and include representatives of the most characteristic of the Palæozoic fossils, the curious crustacea known as trilobites. They were discovered by Dr. Warth in the year 1888. They belong to the genus *Redlichia* which characterizes the Lower and Middle Cambrian. In the sections of the Eastern Salt Range, the Purple Sandstone is seen resting on a great mass of unstratified clay, in the midst of which are situated the layers of salt from which the mountain range derives its name. But the structure of the range is one of extensive overthrust faulting, and it is probable that the Salt Marl is not in its normal situation with reference to the Cambrian strata, but is really much newer, and Tertiary in age.

Cambrian of Spiti

Upper Cambrian fossils were discovered by Mr. Hayden in the upper portion of the Haimanta System of Spiti during the year 1898. These fossiliferous beds, whose aggregate thickness is about 1,000 feet, consist of slates with some quartzites and dolomites. They overlie with apparent conformity some 3,000 or 4,000 feet of unfossiliferous strata recalling the Upper Kadapah, and consisting of slates, some of which are ferruginous and carbonaceous, and of quartzites. These unfossiliferous beds may perhaps represent the Middle and Lower Cambrian. Amongst the fossils discovered by Mr. Hayden, there are trilobites belonging to the genera *Ptychoparia*, *Dikelocephalus* and *Olenus*.

MARINE REPRESENTATIVES OF THE SILURIAN, DEVONIAN AND CARBONIFEROUS.

The Silurian System.

In the Peninsula, the Salt Range, and the Outer Himalaya, there is a great hiatus between the Cambrian and the Upper Carboniferous or Permian. To the east and west of the Himalaya, the mountains of the Arakan Yoma on the one side, and of Baluchistan on the other, do not show any rocks older than Permian or Upper Carboniferous. In order to find typical representatives of the missing formations, we must travel northward beyond the great crystalline axis of the Himalaya, or else eastward beyond its prolongation in the Shan States of Burma.

Silurian of Spiti.

In the Northern Himalaya, in Spiti, the Upper Cambrian is unconformably succeeded by an unfossiliferous quartzite, about 1,500 feet thick, succeeded by highly fossiliferous limestones and calcareous shales of a total thickness of some 500 or 600 feet. Amongst the leading fossils are a number of trilobites belonging to the genera *Cheirurus, Illœnus, Asaphus, Calymene,* and numerous corals, cystoids, brachiopods and gastropods. The fossiliferous beds include both Lower and Upper Silurian horizons (Caradoc to Wenlock).

Silurian of Burma.

In the Northern Shan States of Burma the Lower Silurian is represented by shales of various colours with thick bands of limestones, containing numerous cystideans, bryozoa, brachiopods and trilobites belonging to the genera *Remnopleurides, Calymene, Phomera, Sphœrocoryphe;* and the Upper Silurian consists of strata exhibiting two different facies: an arenaceous facies (Namhsim Sandstone) containing numerous brachiopods, and some trilobites of the genera *Illœnus, Encrinurus,*

Calymene, Cheirurus, Phacops (*Dalmanites*) ; and a calcareous facies (Zebingyi Beds), with graptolites, brachiopods, cephalopods, and trilobites of the genera *Phacops* and *Dalmanites*. The Namhsim Sandstones are principally of Wenlock age, the Zebingyi Beds slightly newer.

Panjal System

The Panjal System of Kashmir probably contains representatives of the Silurian, but, up to now, they have not been differentiated.

The Devonian System.

The Devonian System is doubtfully represented in those portions of the Northern Himalaya that have been surveyed in detail. In the Spiti region, the Muth quartzite, an unfossiliferous band, some 500 feet thick, and an overlying group of limestones between 300 and 400 feet in thickness, may possibly represent the Devonian, the only reason for this supposition being that they overlie beds of undoubted Silurian age, and underlie Lower Carboniferous strata.

Doubtful Devonian beds in Spiti. The Muth quartzite.

The unconformable break at the base of the Permian which is so marked in the regions of Peninsular facies, also affects the northern zone of the Himalaya, though to a less pronounced extent: not only is the Carboniferous sometimes absent in the Spiti region, but in a few instances the Muth quartzite itself has been denuded away previous to the deposition of the "Productus Series" of Permian age.

Devonian of Chitral.

Fossils of undoubted Devonian age have only been found in Chitral and in the Northern Shan States, but in neither case has the stratigraphy been completely worked out.

Eifelian of the Northern Shan States.

The great marine transgression of the Middle Devonian is as well marked in the Northern Shan States as in many other parts of Asia. The Padaukpin limestone of the Northern Shan States has yielded the

richest Devonian fossil fauna as yet discovered in south-eastern Asia. It corresponds with the fauna of the *Calceola* stage of Europe (lower part of the Middle Devonian, or Eifelian), especially with that of its upper portion. Over 160 species have been described, mostly corals, bryozoa and brachiopods, nearly half of which are identical with European species. The facies is identical with that of the brachiopod and coral limestones of the Hildesheim basin. The commonest brachiopods are *Stropheodonta interstrialis* var. *birmanica, Orthothetes umbraculum, Cyrtina heteroclita, Orthis striatula,* and various species of *Atrypa.* The commonest corals are *Calceola sandalina, Cyathophyllum ceratites, Alveolites suborbicularis, Pachypora reticulata, Microplasma fractum, Coenites escharoides.* The leading types of bryozoa are *Fenestrapora isolata* and *Hemitrypa inversa.*

Wetwin Shales.

The Wetwin Shales of the Northern Shan States also contain a Devonian fauna which exhibits a much closer relation to the American Devonian fauna than in the case of the Padaukpin fauna. Judging by their fauna, the Wetwin Shales belong to the Upper Devonian, or the upper part of the Middle Devonian, the "Hamilton Stage" of America. The fauna is not so rich as that of Padaukpin. The most abundant fossils are the Mollusca, the commonest species of which are *Janeia birmanica, Palæoneilo* cf. *plana. Bellerophon shanensis.* Amongst the brachiopods, *Chonetes subcancellata* is particularly abundant.

The Lower Carboniferous. Spiti.

In the region adjoining the lower part of the Spiti valley, there intervenes between the presumed Devonian and the Permian conglomerate a group of shales whose aggregate thickness amounts to over 4,000 feet. In this particular case there seems to be a gradual passage upwards into the Permian conglom-

erate, and it seems that the usual unconformity is locally bridged over, the whole of the Carboniferous System being present in this particular section. Where the maximum thickness is exhibited, the Carboniferous beds underlying the conglomerate have been divided into two sections, each of which is about 2,000 feet thick. The lower division named the Lipak Series is mainly calcareous and shaly, and contains numerous fossil brachiopods, amongst which may be mentioned several species of *Productus*, and the typically Lower Carboniferous *Syringothyris cuspidata*, numerous mollusca, and trilobites of the genus *Phillipsia*. The upper division known as the Po Series consists of quartzites and shales. It contains two sub-divisions, a lower one with a few fossil plants that seem identical with certain plants of the "Culm" of Europe and Australia (Lower Carboniferous), and an upper sub-division with marine fossils, amongst which one notices numerous Bryozoa. These upper beds have been named the "Fenestella shales" from the leading genus of Bryozoa. They are closely connected with the overlying conglomerate, and belong probably to the Upper Carboniferous.

In the district of Rupshu, in the neighbourhood of Spiti, the Lower Carboniferous appears to be represented, but the beds have been much altered by compression and by the contact effects of granitic intrusions, so that the fossils are to a great extent obliterated.

Lower Carboniferous volcanic formation.

Throughout the entire length of the Himalaya, and beyond its western extremity in Hazara, and in the Chinese provinces situated beyond the eastern frontiers of India, one observes at many places a vast development of volcanic rocks whose exact age, in many instances, cannot be defined any nearer than as intermediate between Cambrian and Permian. In

Hazara and in the Outer Himalaya, these volcanic rocks rest immediately upon the Krol system, the equivalent of the Cambrian Vindhyans, and are overlaid by strata of various ages from rhætic or lias to tertiary. In Kashmir they are associated with limestones containing Lower Carboniferous fossils and are immediately overlaid by the Permian.

Subsequently to the Cambrian, the Peninsular and Extra-Peninsular regions part company in their geological history. We have already noticed that after the Cambrian the ocean ceased to overflow the areas of Peninsular facies, and that there are no formations intermediate in age between Cambrian and Upper Carboniferous, either in the Peninsula proper or along the greater part of the Outer Himalaya where the Peninsular facies prevails. It is only quite close to the western extremity of the Himalaya, where the range loses somewhat of what might be called its abnormal or "Himalayan" character, that we observe outside the central crystalline axis, marine representatives of the Lower Carboniferous, and probably of the silurian in the "Panjal" System of Kashmir.

Geological History of India during the Upper Carboniferous, Permian and Mesozoic Periods.

Towards the end of the Middle Carboniferous, there occurred an extensive orogenic upheaval in many parts of the globe. Mountains, which denudation has now removed, were upheaved to an altitude comparable with that of the highest ranges of the present day, and there are indications of the existence of glaciers. Except where sedimentation continued uninterrupted in places that remained unaffected by these movements of the earth's crust, we find, therefore, a well marked stratigraphical break at the base of the Upper Carboniferous, which usually rests unconformably on the underlying rocks. The junction is usually indicated by

Orogenic phenomena in Carboniferous times

an unconformity-conglomerate, which often exhibits peculiar characters indicating glaciation. This break is particularly conspicuous in India where the Lower Carboniferous is unknown except in the Himalayan exposures just mentioned. With this exception the Upper Palæozoic, almost everywhere in India, commences with a peculiar boulder bed which supports an extensive series of Permian strata.

The Carboniferous System in Europe was originally established in order to include all the Palæozoic coal measures of that country. But it has been found on closer study, that in Europe, there is a break just as pronounced and quite as general as in India, above the Middle Carboniferous and that it is situated at the same horizon.

After the great upheaval of the Middle Carboniferous, the crust of the globe remained comparatively quiescent until the middle of the Tertiary era. Throughout the intervening periods we cannot, therefore, avail ourselves of any marked stratigraphical unconformities to establish divisions through that long series of ages. There are, however, indications of certain universal or widespread alterations in the relative level of the ocean that have left their mark in the stratified record, and that greatly assist in demarcating lines of division. Whenever the level of the ocean was comparatively high, its sediments invaded certain areas that had previously been continental. This was particularly the case at the time of the Upper Cretaceous (the period of the Chalk). Whenever the surface of the ocean subsided to an unusually low level, the previously formed sediments were left dry, and sedimentation was interrupted above them until the next return of the ocean. Owing to the wide areas over which they can be recognized, it is these interruptions which have principally been made use of as lines of demarcation between the various systems.

Some of the most conspicuous of these interruptions, for instance, the one between Permian and Trias that separates the Primary from the Secondary, or the one between the Cretaceous and Eocene that separates the Secondary from the Tertiary, are as distinct in India as in Europe. It must be noticed, however, that owing to the quiescence of the earth's crust during these periods, the breaks are unaccompanied by any stratigraphical unconformity. Consequently they easily escape notice, and it has hitherto been the custom to admit that in contradistinction to what is observed in Europe, there is in India a gradual passage from Primary to Secondary, and from Secondary to Tertiary. A closer study of the fossil contents of the rocks has now revealed the universal presence of the statigraphical breaks, at least amongst the marine strata, and their coincidence with those originally established in Europe.

Stratigraphical breaks indicated by lateritic bands.

The occurrence of the ferruginous beds representing a peculiar alteration product of rocks exposed to the air, known as "laterite," often assists in locating these stratigraphical breaks in the absence of a stratigraphical unconformity. These ferruginous layers represent the altered surface of the sediment which was exposed to atmospheric agencies during the interval between two marine invasions.

Northern and Southern continents separated by the Tethys.

The corrugation of the earth's crust that produced the great upheaval of mountain ridges in Middle Carboniferous times also accentuated a deep furrow almost encircling the world, and constituting an ocean, of which the present Mediterranean is the last remnant. This extinct ocean, known in geological nomenclature as the Tethys, completely separated the continents of the

Northern and Southern hemispheres, when it thus became deepened in Upper Carboniferous times. During the Lower and Middle Carboniferous the separation was not so complete, and the lands of both hemispheres supported similar plants and animals. But during the Upper Carboniferous and Permian, all connection was severed, and the southern continent including the Indian Peninsula, parts of South America and South Africa, and Australia, joined together by lands that have now subsided beneath the Atlantic and Indian Oceans, was inhabited by a flora and fauna quite different from that of the northern lands. Something of the same sort is observed at the present day in Australia and New Zealand which, being separated from the rest of the World by a broad expanse of Ocean, are tenanted by different plants and animals.

The contrast between the northern and southern flora was especially pronounced during the Permian. The southern flora is known as the "*Glossopteris* flora" from the name of its most abundant and characteristic fossil, a plant allied to the ferns, and never met with in the normal fossil flora of the northern lands. Several fossil types which became abundant in the Mesozoic flora of Europe are already well represented in the Permian flora of the Southern lands: the southern continent was apparently the original home of certain types that acquired a world-wide distribution in the succeeding Mesozoic era. After the Permian, the contrast between the northern and southern facies gradually fades away owing to the commingling of the flora of both regions, and, by the time of the Lias, the distinction had been practically obliterated.

Marine strata of Upper Carboniferous to Eocene age, largely consisting of shales and limestones, are developed on an enormous scale in many parts of the

extra-peninsular regions of the Indian Empire, and can readily be correlated with those of other parts of the world by means of their abundant fossils. The extra-peninsular regions were then submerged beneath the Tethys, while the Peninsula remained as to-day a continental area. Consequently the marine beds of the extra-peninsular region are represented in the Peninsula by great masses of fluviatile sandstones associated with coal-seams and containing no other fossils but fragmentary remains of plants and terrestrial animals.

The peninsular beds exhibiting this special facies constitute the Gondwana Series whose name is derived from that of the old Gond Kingdoms which occupied the area in which these rocks are most typically developed. The name of Gondwana Series, originally applied to these fluviatile formations in India, has been extended to beds containing a similar fossil flora in South America, South Africa, and Australia; the southern continent of which these lands are the remnants is spoken of as Gondwana-Land. For the Palæozoic (Primary) formations that still remain to be noticed, and for the succeeding Mesozoic (Secondary) ones, it will, therefore, be necessary to examine separately two facies: the Gondwana facies with terrestrial fossils and the marine facies.

Gondwana-Land.

Formation of faulted troughs in Permian times.

In the Peninsula the Permian period was initiated by a set of geotectonic phenomena which constitutes as conspicuous a datum line as the unconformable break in the extra-peninsular area. The Peninsular rocks were no longer susceptible of further folding from tangential pressure; but instead of being affected by tangential displacements such as constitute the overthrusts of an ordinary mountain range, it yielded to *radial* disturbances, (so called because the displacement is along vertical lines directed towards the centre of the earth), that is, certain portions sank bodily in troughs bounded by normal faults.

As mentioned in a previous chapter, the regions along which one observes this subsidence are precisely, in many cases, the zones which, at a previous period, had been areas of special elevation along mountainous axes, as though the orogenic forces had exceeded their goal, necessitating subsequently a negative compensation. The formation of these troughs is by no means a singular phenomenon. Similar features were produced in certain parts of Europe at the same period, the crust of the earth subsiding during Upper Carboniferous and Permian times precisely along certain lines where the rocks had been folded in Middle Carboniferous times. In this manner were formed the coal-basins of Central France in which the coal is of later age than in the British Isles or in the Franco-Belgian basin, while they are partly contemporaneous in age and absolutely identical in structure with the Gondwana coal-basins of India.

Permian glaciation.

In many parts of the world the close of the Carboniferous and commencement of the Permian were marked by glacial phenomena. The causes of wide-spread glaciation like that which occurred in pleistocene times are not yet fully understood, but it is a remarkable fact that the two most pronounced glacial episodes so far known in the earth's history, in Permian and in Pleistocene times, followed the final phase of a great orogenic upheaval. The erection of mountain ranges must be regarded therefore as an important factor in the establishment of wide-spread glacial conditions, a conclusion which, indeed, seems plausible enough as the increased altitude of the land must be a potent factor in the formation of glaciers.

The vast thickness of the Gondwana formation in India indicates a corresponding amount of denudation, and proves that the mean altitude of the peninsula must have been much greater than at the present day. Its loftily situated surfaces became the gathering-ground for snow fields and glaciers which, in some instances, grew to a sufficient volume to descend down to the sea-level without melting. Hence, the sediments of the Gondwana system are everywhere initiated by a formation of glacial origin.

Boulder-bed of the Salt Range.

In the Salt Range one observes a singular boulder-bed resting unconformably on the Cambrian, and underlying the marine Permian strata constituting the "Products Series." The pebbles of this boulder-bed are scattered at irregular intervals through a confused mass of silt and sand grains, without stratification and showing no signs of the sorting agency of running water. The pebbles are often striated and polished in a manner characteristic of ice action, sometimes curiously "facetted," and the underlying floor of Cambrian rocks is deeply grooved. In all its char-

acters this remarkable boulder-bed agrees with a glacial moraine.

Talchir Boulder-bed.

Similar striated pebbles are sometimes observed in the *Talchir boulder-bed* which usually constitutes the base of the Gondwana formation, but the enclosing silts are distinctly stratified, and in all their most typical exposures the Talchir beds show unmistakable signs of deposition in water, probably in lakes. The Talchir boulder-beds cannot therefore be regarded as the actual glacial moraine as in the case of the boulder-bed of the Salt Range, but rather as the moraine material redistributed by water after the final retreat of the ice-sheets. Occasionally remnants of the original moraine have subsisted as for instance near the village of Irai, along the banks of the Pem river close to its confluence with the Wardha, where a confused aggregate of boulders and finer material rests upon a deeply grooved surface of Kadapah limestone. In most instances, however, the Talchir beds do not belong strictly to the period of glaciation but to the period immediately succeeding. They are, therefore, slightly newer than the true glacial boulder-bed of the Salt Range.

Evidence of Permian glaciation in low latitudes outside of India.

The remnants of the Permian glaciation are known not only in India but are scattered over many parts of Australia, Africa, and South America in regions situated in latitudes so low as to have never been reached by the pleistocene glaciation in either hemisphere. In India and in some other localities, the Permian glacial phenomena have affected even the tropical zone. It has been proposed to account for this anomaly by supposing that the axis of the earth occupied a different position in previous geological ages; but the marks of glaciation are scattered over such a wide area that it is impossible to

frame any consistent scheme of the distribution of latitudes that would bring them into the neighbourhood of the poles, not to mention the mechanical difficulties involved in such a supposition.

Absence of climatic zones in ancient geological periods.

We are therefore driven to admit that the Permian glaciation did really affect tropical and sub-tropical latitudes, and this conclusion is in keeping with other indications of a uniform distribution of temperature over all parts of the globe in former geological times: the average temperature along the equatorial zone was probably lower than at the present day, but the poles enjoyed almost the same temperature. Not until the Upper Cretaceous and Tertiary do we observe indications of pronounced seasonal variations and of climatic zones.

With a lower average temperature of the equatorial zone, there is no reason therefore against admitting the development of glacial phenomena, provided they were favoured by a suitable combination of the necessary conditions of altitude and moisture.

Classification and distribution of the Gondwanas.

Three-fold division of the Gondwana.

The Indian Gondwanas include three principal divisions, the Lower, Middle and Upper Gondwanas corresponding respectively with the Permian, Trias and Jurassic. The Lower and Middle Gondwanas are developed on a vast scale, with a thickness of many thousand feet, and are divided into several stages, the Lower Gondwana including the Talchir and Damuda, while the Middle Gondwana includes three stages, the Panchet, Kamthi and Maleri. The Middle Gondwana corresponds with the New Red Standstone of Europe with which it agrees lithologi-

cally. The name Mahadeva is sometimes applied to the entire group of the middle Gondwana.

The Gondwana is the main coal-bearing formation of India, coal-seams occurring both in the Lower and Upper Gondwanas, though the present exploitation is practically restricted to the Lower Gondwana coal.

The triangular Gondwana area.

So far as can be made out in the presence of the Deccan Trap which obscures the older geological features of some portions of the Peninsula, the area over which the Gondwana troughs are scattered along certain very definite lines, has the shape of a vast triangle with slightly curvilinear sides and tapering angles. The main body of the triangle occupies the north-eastern part of the peninsula. One of the tapering angles points towards the Gulf of Cambay at the northern end of the west coast, another towards the coast of Coromandel, in the southern portion of the east coast, while the northern angle reaches the outer zone of the eastern Himalaya in the neighbourhood of Darjeeling.

The Gondwana basins are distributed partly along the sides of the triangle, partly along two "cross bars" uniting the two longer sides of the triangle; one of these "cross bars" coincides to a large extent with the valley of the Damuda river, the other runs roughly parallel to the Mahanadi and Brahmani rivers along a portion of their course. The shortest side of the triangle coincides approximately with the valleys of the Wardha, Pranhita and Lower Godavari. The principal exposures along the northern side of the triangle run parallel with the Narbada and Son rivers south of the Vindhyan range. South of the Narbada they constitute the Satpura hills. The exposures along the eastern side which corresponds largely with the east coast of the peninsula are more discontinuous; the southern point of the triangle is continued by a long succession of

small exposures scattered along the coast for a distance of about 400 miles from the neighbourhood of the Kistna delta up to the Cauvery; there are important exposures near the mouth of the Godavari and that of the Mahanadi, the line is continued further north in the Rajmahal hills, the north-eastern prolongation of the triangle includes the exposures along the Outer Himalaya of Darjeeling and Bhutan. The western angle of the triangle is concealed by the Deccan Trap.

The Upper Gondwanas are largely developed along the sides of the triangle, but are entirely absent from the "cross bars" of the enclosed area which only contain representatives of the Lower and Middle Gondwanas.

The Lower Gondwanas.

Talchir. Two sub-stages.

Of the two divisions that make up the Lower Gondwana, the older one or the Talchir includes two sub-stages, a lower one, the Talchir proper, and an upper one, the Karharbari.

Thickness of the Talchir proper.

The Talchir proper is of moderate and rather uniform thickness, about 500 to 800 feet and more widely spread than any of the other Gondwana divisions though these often far exceed the Talchirs in thickness.

Constitution of the Talchir.

The Talchirs consist of fine-grained arenaceous shales of greenish grey, more rarely of red colour, and fine-grained soft sandstones, greenish grey or reddish, consisting of quartz and undecomposed felspar. The shales are greatly jointed, and break up into angular, often pencil-shaped fragments. They are frequently calcareous. The sandstones are somewhat thickly though distinctly bedded, occasionally interstratified with shales, and often break up into cubic pieces for which reason they have received the name of "tesselated sandstones." The sandstones

usually predominate in the upper portion of the Talchirs, there being a gradual increase in the coarseness of the sediments as one ascends through the section. Occasionally the Talchir sandstones are calcareous and in some instances, in the Wardha valley, these calcareous rocks have weathered in such a manner as to constitute a "flexible sandstone." Pebbles of various dimensions, sometimes reaching the size of large boulders, are frequently scattered through the fine shales or mudstones towards the base of the series, and constitute the Talchir boulder-beds. The pebbles often consist of rocks that do not occur in the neighbourhood of the Talchir exposures in which they are found, and which must have been carried from a distance by glaciers. Yet, the distinct stratification of the shales and sandstones indicates that these beds have been deposited in water and represent redistributed moraine material rather than the original moraine. As already mentioned, instances of true moraine matter with striated pebbles and grooved surfaces of the underlying rock-floor are of rare occurrence, the most remarkable case being that of the Pem river exposure near its confluence with the Wardha.

The Talchir proper is usually barren of coal-seams. The lower strata of the Talchir shales are unfossiliferous, as though at the time they were deposited the climate were still too severe for a luxurious development of vegetable life. The upper strata of the Talchir proper are sometimes fossiliferous and contain a flora which is markedly different from that of the overlying Damuda, the leading forms being various species of *Gangamopteris*.

The Karharbari sub-stage.

The Talchir is usually immediately succeeded with varying degrees of overlap and unconformity by the coal-measures of the Damuda. In a few instances, however, there intervene a varying thickness of strata

with intercalated coal-seams of good quality constituting the Karharbari sub-stage, so-called after the Karharbari or Giridih coal-field in Bengal. In the Giridih coal-field, this sub-stage consists of whitish or palegrey-grits frequently pebbly, with an aggregate thickness of 200 to 460 feet, containing two fine coal seams, the lowest of which is especially thick and continuous.

Karharbari fossils.

The Karharbari sub-stage, especially in its type area in the Giridih coal-field, has yielded numerous fossil plants the most characteristic of which, besides the Talchir species of *Gangamopteris*, are *Neuropteridium validum* and *Voltzia heterophylla*, both of which communicate a remarkable triassic facies to this flora whose age cannot be newer than Lower Permian

Damuda stage.

The Damuda stage is most completely represented in the Raniganj coal-field which may be taken as the type for this division, the differences in other areas consisting principally in the absence or less complete development of the newer sub-stages.

The three sub-stages exhibited in the Raniganj field are in ascending order, the Barakar, Ironstone shales, and Raniganj.

Barakar sub-stage.

The Barakars, with a thickness of about 2,000 feet, consist of coarse conglomerates with white or buff sandstones and numerous coal-seams, the lowermost of which are often very thick. The pebble beds are particularly frequent towards the base of the sub-stage, the sediments becoming gradually finer in an upward direction. The Barakar sandstones are sometimes felspathic, but the felspar grains are kaolinised instead of being undecomposed as in the case of the Talchirs. The Barakar sandstones exhibit a remarkable tendency to become eroded into "potholes"

along river-beds. Beds of valuable China-clay are sometimes intercalated amongst the Barakar sandstones, especially in the Rajmahal hills.

Ironstone shales.

The Ironstone shales, about 1,400 feet thick, are black carbonaceous shales, with numerous bands of clay-iron stone, the ferruginous element occurring in the form of iron carbonate. They sometimes constitute valuable iron ores. The average amount of metallic iron in the clay-ironstones is 39 per cent. Some of the richer bands in the Raniganj coal-field contain as much as 54 per cent.

Raniganj sub-stage.

The Raniganj sub-stage, with a maximum thickness of 5,000 feet which it attains only in the Raniganj coal-field, consists of sandstones, both coarse and fine-grained, mostly felspathic and false-bedded, intercalated with a large proportion of shales, together with coal-seams. The coal-seams are thinner, but more constant than in the Barakar.

Motur and Bijori sub stage of Satpura area

In the Satpura Range the Motur and Bijori sub-stages, with an aggregate thickness of 3,000 to 6,000 feet of sandstones and shales, correspond respectively with the Barakar and Raniganj, but instead of true coal-seams, they only contain intercalations of carbonaceous shale.

In all the other Indian coal-fields outside the Damuda Valley and the Satpura Range, the ironstone shale and Raniganj sub-stages of the Damuda are missing, and the Barakar, when present, is unconformably overlaid by the Middle-Gondwana. The Damuda stage is especially reduced in the Pranhita-Godavari region, where it is only represented by the lower portion of the Barakar, which is scarcely ever more than 400 feet thick, and is fre-

Contraction of Damuda stage in Godavari area.

quently overlapped by the Kamthi beds of Middle Gondwana age, which come to rest directly upon the Talchirs or upon the gneiss.

Physiography of Damuda rocks.

The upper portion of the Barakars consisting of relatively fine-grained material, the ironstone shales, and the Raniganj sub-stage which is to a large extent shaly, are usually weathered to the condition of a slightly undulating plain. The more massive beds towards the base of the Barakar form low hills in the Damuda valley, and rather bold scarps in Central India.

Damuda fossils.

Fossil plants occur abundantly in some of the Damuda strata. The leading fossils are: numerous species of *Glossopteris*; *Schizoneura gondwanensis*, a plant of traissic affinities; *Phyllotheca indica*, one of the most characteristic types of the "Glossopteris flora;" *Sphenophyllum speciosum*, the only typically palæozoic fossil of the Gondwana flora. A stegocephalian of palæozoic affinities, *Gondwanosaurus bijoriensis*, has been discovered in the Bijori beds of the Satpura region, which correspond in age with the Raniganj.

Middle Gondwana.

Absence of carbonaceous element.

The Middle Gondwana rocks never contain any coal-seams or even carbonaceous shale. The leading feature of the group consists in its enormously massive sandstones usually of a bright red colour. In age and in lithological characters, it corresponds with the continental facies of the European Trias, The New Red Sandstone, and also with the red rocks so largely developed beyond the eastern frontier of the Indian Empire, in the red basin of Szu-Chuan, in Yunnan, and in the basin of the Mekong.

Middle Gondwana, the equivalent of the New Red Sandstone.

It includes three stages, which are, in ascending order, the Panchet, the Kamthi (also known as Pachmari), and the Maleri (also known as Denwa). The most conspicuous member is the middle division, or Kamthi, almost exclusively composed of sandstone which constitutes the superb escarpments of the Pachmari and Mahadeva hills in the Satpura range, from which the Middle Gondwana has received the name Mahadeva Series. The underlying Panchet and overlying Maleri or Denwa consist largely of shales.

Stratigraphical Divisions

The Panchet beds have been best studied in the Raniganj basin, where they constitute the underscarp of Panchet hill, the upper crags of which consist of Kamthi sandstone. In the Raniganj field they contain a total thickness of about 1,500 feet, consisting principally of alternations of very false-bedded coarse sandstones and red clays, with the exception of the lowest 250 or 300 feet which consist of grey and greenish grey sandstones and shales, often micaceous and very thin-bedded, and not unlike some of the Talchir beds.

Panchet stage.

The Kamthi stage (named after a town situated close to Nagpur), is essentially a sandstone formation, which, when fully developed, attains a vast thickness. In the Damuda valley coal-fields, where it occurs merely in the form of outliers, we seldom observe as much as 1,000 feet that have escaped denudation; but in the Chhatisgarh area or in Central India it has a total thickness of 3,000 or 4,000 feet; it reaches 4,000 feet in the Godavari region and no less than 8,000 feet in the Mahadeva and Pachmari hills of the Satpura range, where it is locally known as the Pachmari sandstone. The sandstones are usually brightly coloured in various shades of red, and their massive beds constitute immense mural escarpments.

Kamthi stage.

Mural escarpments.

While the Damuda sandstones are generally felspathic, the Kamthi sandstones are usually non-felspathic. They are often argillaceous, but do not contain felspar in various stages of decomposition like the sandstones of the Lower Gondwana; hence their superiority as building materials.

In addition to the sandstones, there occur sometimes intercalations of red, brown, or occasionally white clays, especially towards the base and summit of the formation. Where the underlying Panchet is well developed, one observes sometimes a gradual passage from the Panchet to the Kamthi stage. Frequently, however, the Panchet is missing, and the Kamthi rests unconformably on some division of the Damuda, usually the Barakar. In many localities this unconformity was overlooked during the earlier preliminary surveys, and the Kamthi came to be regarded as the equivalent of the Raniganj, an error that has caused much confusion in the classification of the Gondwanas, and is chiefly responsible for the mistaken impression that the Gondwana fauna exhibits an anomalous assemblage of forms.

Damuda-Kamthi unconformity.

The Kamthi clays are almost always micaceous and ferruginous, and frequently pass into a dense hæmatitic material of a deep purplish-red colour, sometimes rich enough in hæmatite to constitute an iron ore. This heavy hæmatitic rock frequently contains beautifully preserved impressions of fossil leaves along the planes of bedding. These impressions are entirely devoid of carbonaceous material, there being a complete absence of carbonaceous matter throughout the entire thickness of the Middle Gondwana.

Beds of hæmatite clay.

The Maleri or Denwa beds are quite conformable to the underlying Kamthi or Pachmari sandstones in the Satpura

Maleri beds.

area, but there appear to be local unconformities in the Godavari region.

Maleri stage, especially a clay formation

Lithologically the Maleri stage in the Godavari region may generally be described as a clay series with subordinate bands of sandstone.

Middle Gondwana fossils.

Plant-fossils have, so far, been obtained only from the Panchet and Kamthi stages of the Middle Gondwana. The Panchet plants are poorly preserved, and when recognisable, are closely related to or identical with common Damuda forms. The Kamthi flora includes several species of *Glossopteris*, some of which are identical with Damuda forms, while others are special; the most characteristic Kamthi plant is the beautiful fern *Danæopsis Hughesi* which is of special interest as occurring also in the Rhætic beds of Tonkin and the Middle Gondwana of Shensi in China.

Fossil Plants.

Panchet and Kamthi vertebrates.

The Middle Gondwana has yielded a fairly abundant vertebrate fauna. The Panchet stage has yielded stereospondyle amphibians of the genera *Gonioglyptus*, *Glyptognathus* and *Pachygonia*, and anomodont and zanclodont reptiles of the genera *Dycinodon* and *Epicampodon*. The Mangli amphibian, *Brachyops laticeps*, comes from a low horizon of the Kamthi stage, and does not differ much in age, therefore from the Panchet fossils. It is closely related to *Micropholis* from the Upper Beaufort beds of South Africa. The Panchet and Kamthi have yielded abundant remains of *Estheria*.

Maleri vertebrates.

The Maleri or Denwa have yielded fish teeth of *Ceratodus* closely allied to triassic (Lettenkohle) forms of Europe; several "labyrinthodonts" including a *Mastodonsaurus*, forms allied to *Capitosaurus* and *Metopias* of the Upper

Trias of Europe, and a *Pachygonia* identical, perhaps, with the Panchet fossil; various reptiles amongst which a rhynchocephalian, *Hyperadopedon Huxleyi*, parasuchian crocodiles of the genera *Belodon* and *Parasuchus*, and a zanclodont related to the genera *Thecodontosaurus* and *Stegosaurus*.

The whole of this fauna bears unmistakeably the stamp of the Trias, and the three stages of the Middle Gondwanas are approximately equivalent to the three divisions of the European Trias, the Bunter, Muschelkalk, and Keuper.

Upper Gondwana.

Lithology.

The Upper Gondwana consists largely of massive sandstones closely resembling some of the Middle Gondwana rocks, but is distinguished by the presence of coal-seams and a considerable development of limestones, while one of the outcrops, that constituting the Rajmahal hills of Bengal, consists essentially of volcanic rocks.

Distribution.

As already mentioned, the Upper Gondwanas are entirely restricted to the outer border of the great triangular region constituting the Gondwana area. Along the east coast they are associated with marine intercalations often highly fossiliferous which, unfortunately, have only been cursorily examined.

The Upper Gondwanas, as developed in their several areas, have not been sufficiently closely compared with one another for the establishment of a consistent nomenclature.

Rajmahal volcanics.

In the Rajmahal hills they exhibit the exceptional facies of a volcanic series, consisting of some 2,000 feet of basaltic flows, with occasional intercalations of clays, carbonaceous shales, and siliceous porcellanoid shales, which have long attracted attention on account of the abun-

dance of beautifully preserved fossil plants which they contain. These plants constitute an assemblage of liassic facies, the richest fossil flora yet discovered in India, remarkable for the abundance of ferns (principally *Tæniopteris* and *Dicksonites*) and cycads (principally *Ptilophyllum*).

The Rajmahal volcanics rest unconformably upon the Dubrajpur sandstone which corresponds with a portion of the Kamthi stage.

Dykes of Rajmahal age.

The numerous dykes of dolerite and of mica-peridotite which intersect the Lower and Middle Gondwanas in the eastern coal-fields of Bengal belong to the same volcanic system as the Rajmahal lava flows.

The most characteristic and complete development of the Upper Gondwanas is that observed in the Son-Narbada and in the Godavari regions.

Upper Gondwana of Satpura region and Central India.

South of the Narbada river, in the Satpura range, the Upper Gondwanas include two sub-stages of which the lower one, varying in thickness from 50 to 600 or 800 feet, occasionally amounting to 1,000 feet, is known as Bagra, after a fortress situated on the Tawa river, a tributary of the Narbada, while the upper sub-stage is named after the large town of Jabalpur. The Upper Gondwanas are unconformable to the underlying Denwa beds and overlap nearly all the older divisions of the Gondwana series at both extremities of the Satpura range.

Bagra sub-stage.

The lower sub-stage, the Bagra, consists chiefly of irregularly intermixed limestones, clays and sandstones, the latter often conglomeratic. The Jabalpur beds consist principally of massive softish sandstones with subordinate white and pale tinted clays; limestones are exceptional, and lignitic

Jabalpur sub-stage.

coal-seams often occur near the base. The proportion of coal is exceedingly variable, and seldom sufficient to be economically useful.

The Jabalpur beds have yielded a rich flora of Upper Liassic to Lower Oolitic facies. It is usually regarded as slightly newer than the Rajmahal flora.

Upper Gondwana of Pranhita-Godavari region.

The Upper Gondwanas in the Pranhita-Godavari region include two divisions, a lower one constituting the Kota stage, 2,000 feet thick, the equivalent of the Bagra and Jabalpur sub-stages of the Son-Narbada region, and an upper division, the Chikiala stage, 500 feet thick, unrepresented in the Son-Narbada outcrops.

Palæontology of Kota stage.

The plant remains hitherto discovered in the Kota group include *Palissya jabalpurensis* and *Araucarites cutchensis*, both of which are characteristic Jabalpur fossils.

The fish remains abundant in the limestones include species of *Lepidotus*, *Tetragonolepis*, and *Dapedius*, indicating that the age of the rocks is liassic.

Chikiala stage.

The Chikiala beds which constitute the newest stage amongst the Gondwana Series of the Pranhita-Godavari region, consist essentially of light-brown, red, yellow and buff sandstones and heavy conglomerates. All these rocks are at times extremely ferruginous in their constitution, so much so as to become sometimes valuable iron ores.

Lithology of Chikiala stage.

Probable identity with Tripetty sandstone.

The Chikiala sandstones have yielded no recognisable fossils, but there is reason to believe that they are of the same age as the Tripetty sandstones of the coastal region of the Godavari regarded as uppermost Jurassic.

Upper Gondwana of the coastal system.

The Upper Gondwanas very much reduced in thickness are exposed along the coastal plain from the neighbourhood of Ellore to that of Rajamahendri at the head of the Godavari delta They rest directly and quite unconformably upon the Kamthi sandstones without the intervention of the Maleri beds. The lowest division constitutes the Golapilli sandstones consisting of about 300 feet of yellowish-red sandstones, grits and conglomerates. They contain a fossil flora closely related to the Rajmahal flora. They are usually overlaid unconformably by the Tripetty sandstones except at a few places where there intervene some shales and clays with a maximum thickness of 150 feet, known as the Ragavapuram beds, which seem to rest conformably on the Golapilli beds, but are unconformably overlaid by the Tripetty sandstones. They consist principally of white and buff shales, pale-brown shales with purple blotches and white and purple sandy clays. They contain ammonites and other marine fossils which have not yet been identified, and a few fossil plants belonging mostly to common Upper Gondwana species.

Golapilli sandstones

Ragavapuram beds.

Tripetty sandstones.

The unconformably overlying Tripetty sandstones rest upon the Ragavapuram shales or the Golapilli sandstones with the intervention of a bed of laterite. They are about 150 feet thick and consist of dark brown and reddish sandstones, gravel beds and conglomerates, sometimes with concretionary ironstone. They are unfossiliferous in their type area, but some detached exposures supposed to belong to the same formation have yielded species of *Trigonia* regarded as identical with some of the uppermost Jurassic fossils from the Umia beds of Kachh.

The Tripetty sandstones are probably the equivalents of the Chikiala sandstone The Ragavapuram shales and Golapilli sandstones correspond with some portion of the Kota stage.

The Tripetty sandstones are unconformably overlaid by the "infratrappean" and "Deccan" Trap of upper cretaceous age.

Coastal System near Ongole.

Other detached outcrops of Upper Gondwanas occur along the coastal plain between the Kistna river and the town of Ongole. Where the section is most complete, near the village of Budavada, 24 miles N. by E. of Ongole, the shales are intercalated between two masses of sandstones, the lower mostly buff-coloured being known as the Budavada beds, the upper red and brown sandstones constituting the Pavalur beds, while the intermediate shales are known as Vemavaram beds. The Vemavaram fossil flora is, after that of Rajmahal, the richest of the Upper Gondwana floras It is closely related to the Jabalpur flora.

Pavalur, Vemavaram, and Budavada beds.

Fossil plants in Vemavaram beds.

Coastal System near Madras.

Still further south along the coastal plain, near Madras, there are some more exposures of Upper Gondwanas. They include two divisions, a lower one constituting the Sripermatur beds and an upper one known as the Sattavedu beds.

Sripermatur beds.

The Sripermatur beds include sandstones and generally buff-coloured clays and shales containing fossil plants and marine shells. The latter have not been studied. The rich fossil flora is closely related to those of Vemavaram and of Jabalpur. Some of the clays are useful for ceramic purposes.

The Sattavadu beds are probably the equivalents of the Pavalur, Tripetty, and Chikiala sandstones. The Sripermatur beds evidently correspond with the Vemavaram beds and a part of the Kota stage.

Atgarh sandstone near Cuttack.

There is an exposure of Upper Gondwana rocks in the neighbourhood of Cuttack at the head of the Mahanadi delta. This area is known as the Atgarh basin from the name of a town situated 14 miles west by north of Cuttack. The rocks consist principally of grits, sandstones, and conglomerates, with subordinate beds of white, or pinkish or red clay.

Building stones from Atgarh basin.

The Atgarh sandstones have supplied the material for the magnificent temples of Bhuvaneshvar, Puri (temple of Jagannath), and Konarak (temple of the Sun or "black pagoda") all of which are situated in the alluvial coastal plain east and south of the Gondwana outcrop.

The Buddhist caves of Kandagiri, 15 miles south of Cuttack, are carved out of a cliff of massive sandstones of the same series.

MARINE PERMIAN AND UPPER CARBONIFEROUS.

Distribution of post-Carboniferous marine beds.

In the geosynclinal areas of extra-Peninsular India, there is a well-marked unconformity at, or just below the base of the Permian, owing to which the Devonian and Carboniferous are often incomplete, while in the Peninsular area, there is a total absence of any formations intermediate between the Vindhyans of Cambrian age and the Permian Lower Gondwana. Extensive sedimentation was resumed with the Permian, and the geosynclinal areas exhibit a remarkably complete succession of marine strata extending in age from Permian to Miocene, the various divisions being often represented by sedimentary accumulations of enormous thickness that were deposited on the gradually subsiding floor of the Tethys.

Along the borders of the Peninsula, the same formations are often represented by marine beds of coastal facies, frequently exceedingly fossiliferous. The distribution of these coastal formations indicates that at as early a period as the Jurassic, the Peninsular area had already acquired practically the same outline as at the present day, the periods represented by coastal deposits usually coinciding with widespread marine "transgressions."

Permian of the Salt Range.

In the Salt Range situated close to the border-line between the Peninsular and extra-Peninsular regions, marine beds exhibiting the coastal facies are largely developed. The Permian is exceptionally well represented, and its development in the Salt Range constitutes the main type of reference for the marine facies of that system not only for India, but for all other parts of the world.

The stratigraphical gap in the Salt Range is the same as in the Peninsula: there are no beds intermediate in age between the Cambrian and Permian or uppermost Carboniferous.

The well-known "boulder-bed" probably Upper Carboniferous in age, rests unconformably on various stages of the underlying Cambrian. In places where the section is complete, the Upper Carboniferous and Permian of the Salt Range, with an aggregate thickness varying from about 700 to 1,000 feet, include two approximately equal divisions, a lower one which is chiefly arenaceous, and an upper one chiefly calcareous. Although the thickness of strata is about the same, the two divisions represent very different intervals of geological time. The various subdivisions of the lower arenaceous group are inconstant and are frequently observed to be mutually representative as the formation is followed from place to place. The rocks are mostly coarse grained, a considerable proportion of their total thickness being often contributed by the peculiar boulder-bed which may reach a thickness of 200 feet. There is reason to believe that this lower group of strata represents only a relatively small portion of the uppermost Carboniferous.

Stratigraphical divisions of the Permian and Upper Carboniferous in the Salt Range.

Arenaceous sub-division.

Boulder-bed.

The upper calcareous group differs greatly from the lower arenaceous one owing to the great constancy of its subdivisions, and, instead of being restricted, in time, to one relatively short geological period, it embraces representatives of the entire Permian system. The lower arenaceous group contains few fossils and these belong to a somewhat peculiar type: the upper calcareous group is

Calcareous sub-division or Productus Limestone.

crowded with fossils, and owing to the abundance of brachiopods belonging to the genus *Productus* is known as the Productus series. Owing to the prevalence of a red or purple sandstone with greenish or purplish patches, the lower arenaceous division is usually spoken of as the Speckled sandstone series, except towards the eastern extremity of the Salt Range where it assumes the somewhat different facies of the "Olive Series."

The Upper Carboniferous and Permian of the Salt Range may be tabulated as follows.—

Main Divisions.		Sub-stages.	Approximate thickness in feet
PRODUCTUS LIMESTONE GROUP.	Upper Productus beds.	Chidru beds.	16—25
		Kundghat beds, mainly sandstone (Bellerophon beds.)	100—125
		Jabi beds (transitional) (50′)	
	Productus limestone proper, or Middle Productus beds.	Kalabagh	200—350
		Virgal	
	Lower Productus beds.	Katta beds, calcareous sandstone and arenaceous limestone (about 50′)	
		Amb beds, calcareous sandstones.	20—50
SPECKLED SANDSTONE GROUP.		Lavender clay (50-100′)	200—400
		Speckled sandstone.	
		Boulder-bed	100—200
Olive Series, about 150ft.			

The Olive Series.

Near the eastern end of the Salt Range the Upper Palæozoic is represented only by the "Olive Series" consisting of

dark-greenish, greyish, white-and-yellow striped, yellow-and-grey spotted, or olive or whitish sandstones. In the lower part are strong conglomerates, or else boulder-beds consisting of thick, dark shales, simulating in appearance a volcanic tuff, and filled with boulders. The enclosed fragments are mostly of crystalline rocks and sometimes attain large dimensions. In certain cases the boulder-beds associated with the "Olive Series" may represent redistributed glacial material in the same way as the boulder-bed of the Peninsular Talchir. In other cases, however, the boulder-bed at the base of the Olive Series, like that at the base of the typical Speckled Sandstone further west, actually represents an original glacial moraine. The facies is very similar to that of the Talchir beds at the base of the Gondwana series.

Similarity to Talchir.

Certain thick, greenish-olive, deeply weathered sandstones, enclose considerable numbers of the casts of large bivalves of the genus *Eurydesma* represented by several species identical with fossils occurring in association with the Upper Carboniferous or Permian glacial beds of Australia.

Australian fossils.

The boulder-bed often exhibits a close resemblance to a pleistocene "boulder clay." Not only are the pebbles polished and striated in the manner characteristic of glacial action, but the underlying floor of the Cambrian rocks is also typically grooved, for instance, in the neighbourhood of Makrach. About one mile north-west of Kheura (a locality famous for its salt mines, situated 4 miles north of Pind Dadun Khan), the boulder-bed rests upon the Salt Pseudomorph Zone of the Cambrians, whose flaggy layers are observed to have been torn up by the force of the glacier, huge irregular slabs being confusedly incorporated amidst the lower portions of the boulder-bed.

The Boulder-bed.

Pebbles derived from the Aravalli region.

Lithologically the pebbles included in the boulder-bed of the Salt Range are identical with many of the rocks constituting the Aravalli Range and Western Rajputana, the Malani rhyolites in particular being easily recognisable. These fragments must have travelled, therefore, over a considerable distance from a region situated several hundred miles south-east or south-south-east of the Salt Range. The Aravalli region, in late Carboniferous times, must have been occupied by an ice cap sending forth a glacier of sufficient magnitude to reach the sea-coast.

"Facetted pebbles" of the Salt Range.

In addition to the ordinary striated boulders, one observes peculiar polyhedral pebbles known as "facetted pebbles," the different faces of which are polished planes as though the pebble had been shifted in position several times while being subjected to the grinding agency that gave rise to these plane surfaces. Professor Koken has suggested that this action took place by internal movements within the mass of the frozen moraine, and that the pebbles were shifted during a momentary thawing of the glacial material.

Boulder-beds of Rajputana.

Boulder-beds similar to the boulder-bed of the Salt Range are met with at Bap and at Pokaran west of the Aravalli Range in Western Rajputana.

Australian fauna of the "Conularia nodules."

At certain places the boulder-bed passes into a true marine sediment of calcareous sandstone with calcareous concretions enclosing well-preserved fossils. They are generally spoken of as the "*Conularia* nodules" on account of the frequency of this fossil. As in the case of the bivalves from the "Olive Series" facies, these fossils which in addition to *Conularia* include *Pleurotomaria*,

Bellerophon, Sanguinolites, Pseudomonotis, Spirifer, Martiniopsis, Chonetes, are represented by a large proportion of species identical with forms first observed in the marine beds intercalated with the Upper Palæozoic glacial formation of Australia.

Amb beds.

The Amb beds consist of some 50 to 70 feet of coarse, light-coloured, yellowish-grey and greenish sandstones of Talchir facies, intercalated with numerous layers of coaly laminæ, and a band of sandy calcareous shales, and containing the fauna of the "Lower Productus Limestone."

Their uppermost layers are in places highly fossiliferous and abound with *Fusulinæ*.

Fusulinæ are abundant also in the overlying Katta beds, including a moderate thickness of highly calcareous sandstones or arenaceous limestones forming a transition between the Amb sandstones and the Productus limestone.

Katta beds.

The Productus limestone proper varies in colour from grey to black, and several of the magnesian bands are of a warm yellow colour.

Virgal and Kalabagh beds.

The main mass is a crinoidal limestone, while the lower part is either sandy, or else cherty and full of corals.

The lower part of the Productus limestone proper constitutes the Virgal beds; the upper portion constitutes the Kalabagh beds.

Kundghat and Jabi beds.

Above the main mass of the Productus limestone sandy strata reappear constituting the Kundghat beds about 100 feet thick. The transitional beds at their base are known as the Jabi beds. The Kundghat sandstones are intercalated with coaly shales and argillaceous beds. Intercalations of limestones also occur.

These upper beds abound in Bellerophons, one thick sandstone band especially being crowded with *Euphemus indicus*, Waag, and *Bellerophon Jonesianus*, de Kon.

Chidru beds.

The uppermost portion of the Productus Series constitutes the Chidru beds, principally marls and sandstones. Their total thickness is small, not more than 16 to 25 feet, but the sub-stage is interesting owing to its abundant fauna of lamellibranchs. These fossils are usually contained in concretions scattered through a soft light-yellow sandstone, overlaid by a small thickness of unfossiliferous beds upon which the Lower Trias is in its turn superimposed. These uppermost unfossiliferous beds vary a great deal in their constitution, including marls and sandstones, sometimes with impure coal, and are sometimes absent; an unconformity conglomerate is sometimes observed at the base of the Trias. It seems evident that a certain amount of erosion has taken place between the Permian and Trias.

The Zewan beds.

The equivalents of the Productus Series are well developed along the entire length of the geosynclinal zone of the Inner or Northern Himalaya, and also in Kashmir.

The Permian System in the Kashmir valley proper has long been known as the "Zewan beds." The Zewan beds rest upon the palæozoic volcanics of carboniferous age that have already been mentioned in a previous chapter. At the type locality, Zewan, they include a lower division mainly arenaceous, and upper division, principally calcareous and shaly. The lower division, nearly 200 feet thick, consists of alternating sandstones, shales, with subordinate limestones and conglomerates, and beds of impure coal, with Gondwana plant remains. At Khunmu, 15 miles south-east of Srinagar, these plant-bearing beds have yielded a true *Archegosaurus*, indicating that their age must be Lower

Permian. Resting upon the plant beds are some 50 or 60 feet of shales with limestone intercalations; they are crowded with Bryozea, the commonest form amongst which is *Protoretopora ampla* also found in the Fenestella-shales of Spiti, and they also contain *Lyttonia* and various species of *Productus* indicating the same horizon as the Productus Limestone of the Salt Range.

Permian of the Northern Himalaya.

Along the northern zone of the Himalaya, the equivalents of the Productus Series include two different facies: a more southerly coastal facies principally calcareous and shaly deposited near the border of the geosynclinal area, and a more northerly calcareous facies deposited further from the coast The coastal arenaceous facies is known as the Himalayan facies; the northern calcareous development constitutes the Tibetan facies, and has only been observed amongst the shattered stratified masses broken through by volcanic rocks of upper cretaceous age along the frontier between Tibet and Kumaon where one observes a gigantic volcanic breccia in which the fragments vary from the size of mere pebbles to that of single rock masses of the size of mountains Two peaks, those of Chitichun I and Malla Sangchha consist of a massive Permian limestone that has yielded a rich fossil fauna of Kalabagh age

Himalayan and Tibetan facies.

The Himalayan coastal facies has been observed all along the northern zone of the Himalaya. It constitutes the Kuling Series whose stratigraphical succession is very uniform. Its newest and most constant member is constituted by the black "Productus shales" varying in thickness from 150 to 250 feet, whose age is Upper Permian. In Byans, in Garhwal, in Niti, they rest directly upon the "Muth

Kuling Series.

quartzite" which is probably of Silurian age; but in the Lipak valley in Spiti, where the Carboniferous is well represented, there are about 600 or 700 feet of strata conformably underlying the Productus Shales, and intervening between them and the undoubted carboniferous. Above the "Po Series" of sandstones and shales, of undoubted carboniferous age, whose lower beds contain fossil plants of Culm facies there occurs a thickness of some 100 or 150 feet of shales with arenaceous intercalations known as the "*Fenestella* shales" from the leading type of bryozoa which they contain; they also contain *Protoretopora ampla*, the leading fossil of the *Protoretopora* shales of the Zewan beds which perhaps belong to the same horizon. The Fenestella shales are overlaid by some four hundred feet of unfossiliferous shales and sandstones passing upward into a conglomerate of small pebbles; this is succeeded by about 120 feet of calcareous sandstone with a few fossils of Upper Permian facies.

Upper Carboniferous and Permian of Burma, Tenasserim and Balúchistán.

Fusulina-limestones of Upper Carboniferous or Permian age have been observed in the Shan States of Burma. The Schwagerina beds of Tenasserim associated with coal-seams are probably Upper Carboniferous. Fusulina limestones have also been observed in the Pishin and Zhob district of Balúchistán

The equivalence of the Salt Range Permian compared with that of other countries and other parts of India is expressed in the following table:—

	Salt Range.	Equivalents in other Regions.		Gondwana Series.
LOWER BUNTER (LOWER SCYTHIAN.)	Lower Ceratite limestone.	Otoceras, Ophiceras, and "Meekoceras" beds of the Himalaya; Ussuri beds; Lower Werfenian.		LOWER PANCHET
ZECHSTEIN or THURINGIAN	Uppermost zone, apparently absent from the Salt Range and Himalaya.	Upper Zechstein of Germany; Upper part of the Bellerophon Beds; Tatarian stage; Upper Raniganj.	*Bellerophon beds of the Alps.*	RANIGANJ
	Chidru	Base of Upper Zechstein; bivalve beds of the Araxes.		
	Kundghat	Middle Zechstein; Magnesian limestone of England; Kuling stage.		
	Jabi	Otoceras beds of Julfa; Kupferschiefer of Germany; cupriferous sandstone of Russia.		IRONSTONE SHALES
ROTHLIEGENDE or PUNJABIAN	Kalabagh	Chitichun; Productus limestone of Timor; oolitic limestone and lower zone of the Brachiopod-Limestone ($P_a^{\alpha}{}_{g}$) in the Governments of Vladimir and Kostroma.		BARAKAR
	Virgal	Fenestella shales of the Zewan beds (and (?) of Spiti); Fusulina limestones of Sosio; Kungur beds of the Ural and Timan.		
ARTINSK (PERMO-CARBONIFEROUS)	Katta	Lebach beds.	Artinsk beds of the Ural and Timan. Plant-bearing beds of Kashmir.	KARHARBARI
	Amb	Cusel beds; Trogkofel beds.		TALCHIR
UPPER URALIAN	Lavender clays, Speckled sandstone, and boulder-bed.	Schwagerina beds of Russia and of the Alps; Upper Ottweiler beds; [(?) Fenestella shales of Spiti]; Bap and Pokaran beds.		

MARINE REPRESENTATIVES OF THE TRIAS.

Distribution of Marine Triassic Rocks.

The marine representatives of the Trias are superbly developed along the geosynclinal zone of the northern Himalaya where a number of able scientists amongst whom special mention should be made of Stoliczka, Griesbach, Middlemiss, Diener, von Krafft and Hayden, have accomplished the most brilliant geological work as yet achieved in India.

Trias of the Himalaya.

The Permian of Kashmir is everywhere overlaid by triassic beds including all the sub-divisions of the system from lower to uppermost Trias.

Trias of the Salt Range.

In the Salt Range, the Triassic system is reduced to the Lower Trias and the lowermost zone of the Middle Trias, but is distinguished by a richness in fossils unequalled in any other part of the world.

Trias of Balúchistán.

In the Trans-Indus extension of the Salt Range, west of the Indus, the Trias gradually increases in thickness and includes representatives of the Upper Trias, while still further to the south-west, in the Zhob and Pishin districts of Balúchistán, the system is represented by a vast thickness of slaty shales with thin seams of limestone in which only the Upper Trias has been identified.

Trias of the Arakan Yoma.

The same upper Triassic horizon assumes a very similar facies in the Arakan Yoma of Burma, that is the range of mountains situated west of the Irawaddi between that river and the Bay of Bengal.

	Ammonite Zones	Stratigraphical succession.	Approximate thickness in feet.	Himalayan equivalents.
CARNIC.		Crinoidal dolomite	250'	? Halobia beds.
MUSCHEL-KALK.		Sandstone with bivalves.	30' to 100'	? Daonella beds and beds with *Spiriferina Strachey*
MUSCHEL-KALK.	*Stephanites superbus.*	Upper Ceratite limestone.	20'	Hard nodular limestone.
LOWER TRIAS. BUNTER OR SCYTHIAN.	*Flemingites Flemingianus.*	Upper Ceratite sandstone.	30'	Hedensoomia beds.
LOWER TRIAS. BUNTER OR SCYTHIAN.	*Flemingites radiatus.*	Stachella beds ..		
LOWER TRIAS. BUNTER OR SCYTHIAN.	*Ceratites normalis.*	Lower Ceratite sandstone.		
LOWER TRIAS. BUNTER OR SCYTHIAN.	*Proptychites trilobatus.*	Ceratite marls	20' to 30'	Ophiceras, Prionolobus and Otoceras beds.
LOWER TRIAS. BUNTER OR SCYTHIAN.	*Proptychites Lawrencianus.*			
LOWER TRIAS. BUNTER OR SCYTHIAN.	*Gyronites frequens.*	Lower Ceratite limestone.	10'	

A feature of particular interest is the abundance of bellerophons of the genus *Stachella*, representing stragglers from the Palæozoic fauna, in the midst of the Ceratite sandstone.

Trias of Balúchistán.

In the Pishin and Zhob districts of Balúchistán, the dark greenish-grey slaty shales and intercalated thin runs of black limestone, amounting in thickness to several thousand feet that represent the Upper Trias, occupy a vast elliptic area about 70 miles in length from east to west, by 12 miles in width. They rest upon fusulina limestone and appear to belong entirely to the Noric stage, the upper portion of the Upper Trias. They contain specimens of *Monotis salinaria* in great abundance, and a few ammonoids belonging to the genera *Didymites*, *Halorites* and *Rhacophyllites*.

Prevalence of Noric stage.

Trias of the Arakan Yoma.

The Upper Trias is developed in the Arakan Yoma with a very similar facies to that of Balúchistán. According to Mr. Tipper, the fossils include *Halobia* and *Monotis*.

MARINE EQUIVALENTS OF THE JURASSIC.

Geosynclinal and coastal facies.

The marine Jurassic attains a vast development in India where it is represented by two principal facies, the geosynclinal facies and the coastal facies. The geosynclinal facies is developed on a gigantic scale in Balúchistán, in the Inner Himalaya, and north of the Himalaya in Tibet. The fullest development of the coastal facies is in Kachh, in Rajputana, and in the Salt Range, while marine intercalations are also observed amidst the Upper Gondwanas of the east coast of the Peninsula

Calcareous facies

In the Inner Himalaya of Spiti, Garhwal and Kumaon, the greater part of the Jurassic assumes the character of a massive limestone 2,000 or 3,000 feet in thickness, forming inaccessible cliffs. A similar calcareous development is observed along the outer zone of the Iranian arc in Balúchistán, a region where all the geological divisions from Jurassic to Oligocene exhibit a tendency to assume the shape of massive limestones, and which is, for this reason, known as the "calcareous zone." Beyond the Inner Himalaya, in Tibet, and beyond the calcareous zone of Balúchistán, in Afghánistán, southern Seistán and eastern Persia, the constitution of the Jurassic becomes more varied and less exclusively calcareous.

Shaly facies.

Tibetan facies of the Lias.

The Tibetan facies of the Lias as revealed by the blocks contained in the volcanic breccia of Kiogarh five or six miles north-west of Chitichun, includes very earthy, brick-red, thin-bedded, nodular limestones, exhibiting the same lithological and

faunistic identity with certain Alpine facies of Europe, as in the case of the corresponding blocks of Hallstatt-like triassic marble.

The Callovian unconformity.

The geosynclinal and coastal facies of the Jurassic exhibit a curious instance of the compensations between marine regressions and transgressions, such as have been advocated by Haug. The sequence in the geosynclinal facies is invariably interrupted by a stratigraphical gap at the Callovian, the series being resumed either with the Kimmeridge or the Neocomian with varying amounts of slight structural unconformity. The unconformable junction is invariably characterised by the presence of a ferruginous laterite. In the coastal facies of Kach and the Salt Range there are no marine representatives of the Lias, while the Middle Jurassic is poorly represented or absent, and the series acquires a decided marine character only with the Callovian precisely at the same horizon where the sequence in the geosynclinal facies is interrupted.

In the Himalaya, the Callovian unconformity is succeeded by the Spiti shales of Kimmeridge to Portland age passing conformably upward into the Neocomian Gieumal sandstone. In Balúchistán, the Callovian is immediately succeeded by rocks of Neocomian age known as the "Belemnite Shales." The transition between these two types of succession is observed in the mountains of Hazara, and is not gradual, but affects two parallel zones, a northern or rather north-westerly zone showing the Himalayan succession with the Spiti shales, and a south-easterly zone in which the Middle Jurassic is immediately succeeded by the Neocomian. The limit between these two types is so well defined that the Himalayan and Balúchistán type of succession are sometimes observed on opposite sides of the same strike valley. This abrupt transition suggests

that the true explanation of the Callovian unconformity must be sought in an orogenic movement of moderate amplitude affecting precisely those structural lines along which the Himalayan upheaval was to take place in Tertiary times.

Massive Jurassic limestone of the Himalaya.

In the Inner or Northern Himalayan zone of Spiti, Garhwal and Kumaon, the Rhætic, Lias and Middle Jurassic are represented by a vast thickness of 2,000 feet or more of massive limestones constituting mural precipices too inaccessible for close study. Their gradual passage downwards into the Upper Trias, and the presence of Callovian fossils in their uppermost layer indicate that they include representatives of the Jurassic from the Rhætic to the Callovian.

Sulcacutus beds.

The highest beds of the limestone immediately underlying the Spiti shales contain belemnites, bivalves, and brachiopods of Callovian age. They are known as the *Sulcacutus* beds from the name of the prevailing belemnite, *Belemnites sulcacutus*, one of the group of *bisulcati*.

Spiti shales.

Throughout the Inner Himalayan zone, and a part of Hazara, the uppermost Jurassic stages assume the form of the well-known Spiti shales. In the Inner or Northern zone of the Himalaya, their thickness varies from 500 to 1,000 feet. In Hazara it dwindles to about 150 feet. Their outcrop has been traced along the geosynclinal zone from the Yaru plain north of Sikkim through Nepal, Kumaon, Ngari Khorsum, Spiti, up to Kashmir and the western extension of the Himalayan axis in Hazara. The lithological character of the rocks never once varies throughout the enormous length of this outcrop for about 1,000 miles.

In the Himalaya the Spiti shales usually occupy a loftily-situated belt at an average altitude of 15,000 to

17,000 feet contrasting by its open character and gentle slopes with the gigantic precipices and narrow gorges which it overlooks on the southern side.

Sub-divisions of Spiti shales.

Where fully developed, the Spiti shales include three divisions which are, in ascending order, the *Belemnites Gerardi* beds, the Chidamu beds and the Lochambel beds. The bulk of the formation consists of black or blue-black shales with calcareous concretions, each of which usually contains a beautifully preserved ammonite, or sometimes a fossil belonging to some other zoological group. The only exception is in the case of the Lower Spiti shales or *Belemnites Gerardi* beds which are of a grey colour and in which the concretions are unfossiliferous. The ammonites of the Middle Spiti shales or Chidamu beds belong principally to the genus *Perisphinctes* and also include *Oppelia*, and, rarely, *Lytoceras* and *Phylloceras*. The Chidamu beds are of Kimmeridge age; the underlying beds with *Belemnites Gerardi* may be also Kimmeridgian, or may reach downwards into the Sequanian.

Belemnites Gerardi beds.

Chidamu beds.

Lochambel beds.

The Upper Spiti shales or Lochambel beds contain innumerable specimens of *Hoplites* and *Holcostephanus*. Their age is Portlandian including the Berriasian, and they pass conformably upwards into the overlying Gieumal sandstone of Neocomian age.

The Jurassic system in Balúchistán.

In the calcareous zone of Balúchistán, the Lias (Lower Jurassic) consists of 3,000 or 4,000 feet of black limestones, some of them oolitic, others crinoidal, and calcareous shales, with some highly fossiliferous bands, in which the principal sub-divisions of

the European series have been identified. They are succeeded by an equal thickness of massive limestones of Middle Jurassic age, which constitute the Takht-i-Suleiman, the lofty peaks that surround Quetta, and other bulky mountains in the calcareous zone. This massive limestone is unconformably overlaid by the Lower Cretaceous, the Supra-Jurassic series being absent from Balúchistán.

Liassic and Middle Jurassic limestones.

Where the series is most complete, the uppermost beds of the massive limestone become slightly flaggy and contain fossils of Callovian age, especially huge specimens of *Macrocephalites macrocephalus* and *M. Polyphemus*, for which reason they are known as "*Polyphemus* beds." These are overlaid by the Neocomian or other stages of the Cretaceous, while elsewhere the Neocomian rests directly on various horizons of the massive Limestone or even on the Lias, the missing beds having either been denuded away during the interval between the Callovian unconformity and the Neocomian, or else never deposited. The unconformity is everywhere marked by a bed of laterite.

Polyphemus beds.

East of the Irawaddi, as has already been mentioned, there is an almost complete absence of any representatives of the Jurassic system, whether Marine or Continental, and it is evident that a large portion of Indo-China and Southern China must have remained dry land from early Jurassic times to the present day. Nevertheless there occur some instances of marine beds of Rhætic which are of particular interest owing to their contemporaneity with the fluviatile beds of Tonkin containing Upper Gondwana coal-seams and a fossil flora consisting of plants of liassic facies with an admixture of Middle Gondwana

Absence of Jurassic east of the Irawaddi.

Rhætic of Indo-China.

types. The latter element which is absent from the Rajmahal flora indicates that the Rhætic plant-beds of Tonkin must be older than the Rajmahal beds, which, therefore, as mentioned in the chapter dealing with the Gondwana system, should be attributed to the Lias or Lower Oolite.

Rhætic of the Shan States.

The Rhætic of the Northern Shan States consists of contorted calcareous shales which, like many other calcareous rocks of various ages in the Shan plateau, weather into a pale buff friable porous substance. It is only in this friable weathered form of the rock that the fossils become visible, usually as external casts, and their study is a work of considerable difficulty.

Rhætic fauna.

The fossils, mainly lamellibranchs, collected by La Touche and Datta, have been lately studied by Miss Healy (*Palæontologia indica*, New Series, Vol. II, Part 4, 1908), and include the characteristic Rhætic forms *Avicula contorta*, *Grammatodon Lycettii* and *Gervillia præcursor* together with some unexpected survivors from the Palæozoic, such as *Conocardium*, *Modiolopsis* and *Palæoneilo*.

Coastal facies of the Jurassic. The Coastal System.

The bulk of the Indian Peninsula has remained a land area since Silurian times. Its present limits were approximately outlined in Jurassic times, and only along the coastal regions do we find marine sediments representing the traces of successive marine transgressions from Jurassic to Oligocene or Miocene and Pleistocene. These various beds are usually richly fossiliferous and consist of various detrital rocks, sandstones, clays and limestones, and constitute a special group which may be designated as the Coastal System. The beds usually dip away from the higher land of the Peninsula and towards the coast, the newer formations being nearest

the coast. As a rule, their thickness is very moderate as compared with the enormous sedimentary accumulations of the geosynclines, and they generally occupy a narrow belt in consequence of the rising slope of the Peninsular area at a short distance from the coast. Along the north-western margin of the Peninsula there is a large expanse of lowland over which the marine beds of the coastal system occupy a considerable area, especially in Western Rajputana where, however, they are largely concealed by pleistocene and recent alluvial deposits whose accumulation has been favoured by the same flatness of the land that accounts for the great development of the marine beds.

Stratigraphy and distribution of the Coastal System.

The Salt Range, although its beds have been tilted at the time of the Himalayan upheaval, is not a typical geosynclinal area, and its mesozoic marine beds exhibit the coastal rather than the geosynclinal facies.

In Kachh the Jurassics are developed on a scale of thickness quite unusual for the coastal system. This, however, does not indicate a geosyncline, but results from a structure similar to that of the Gondwana basins: the strata occupy a faulted trough tilted on one side, the general dip being southward, only the trough was invaded by the ocean instead of being merely filled up with fluviatile deposits.

It has already been mentioned that, in point of age, the Jurassic beds of Kachh exhibit a curious contrast with those of the extra-peninsular region, the stages chiefly represented in the extra-peninsular being absent from Kachh, and *vice versâ*.

Jurassic of Kachh.

The system is represented in Kachh chiefly by the Upper Jurassic which passes conformably upwards into the Lower Cretaceous. The Jurassic and Lower Cretaceous include the following divisions:—

JURASSIC AND LOWER CRETACEOUS OF KACHH.

	Stratigraphical Succession.	Approximate thickness in feet.	Geological age.
UMIA.	Beds with *Crioceras* and *Acanthoceras*.	3,000′	APTIAN.
	Sandstones and shales with *Cycadeæ* and other plants.		BARREMIAN.
	Sandstones and conglomeritates with marine fossils *Perisphinctes eudichotomus*, *P. frequens*, *Trigonia Smeei*, *T. ventricosa*, etc.		NEOCOMIAN. PORTLANDIAN.
KATROL.	Sandstones and shales with *Phylloceras ptychoicum*, *Oppelia trachynotus*, *Perisphinctes torquatus*, *P. Pottengeri*, etc.	1000′	KIMMERIDGE.
	Red ferruginous and yellow sandstones (Kantkot sandstones) with *Stephinoceras Maya*, *Aspidoceras perarmatum*, *Perisphinctes virguloides*, *P. lemocymon*.		SEQUANIAN.
	Oolites (Dhosa oolite) with *Stephanoceras polyphemus*, *Perisphinctes indogermanus*, *Aspidoceras perarmatum*, *A. babeanum*, *Peltoceras arduennensis*, etc.	50′	OXFORDIAN.
CHARI.	White limestones with *Peltoceras athleta*, *Oppelia bicostata*, etc.	25′	CALLOVIAN.
	Shales with ferruginous nodules, with *Perisphinctes obtusicosta*, *P. anceps*, *Harpoceras lunula*, *H. punctatum*, etc.	1000′	
	Shales with calcareous bands and locally with golden oolite: *Macrocephalites macrocephalus*, *M. tumidus*, *M. bullatus*, *Oppelia subcostaria*, *Perisphinctes funatus*, etc.		

JURASSIC AND LOWER CRETACEOUS OF KACHH.—*Contd.*

	Stratigraphical Succession.	Approximate thickness in feet.	Geological age.
PATCHAM.	Light grey limestones, and marls with *Oppelia serrigera*, Corals and Brachiopoda, etc.	500′	BATHONIAN.
	Yellow sandstones and limestones, with *Trigoniæ Corbulæ*, *Cucullææ*, etc.	500′	

Neocomian age of the Umia flora.

The Umia plant-beds whose intercalation between the uppermost Jurassic beds with numerous Trigoniæ and the overlying beds with Aptian ammonites establishes their Neocomian age, contain a rich fossil flora which agrees far less closely with the oolitic flora of Europe than the Upper Gondwana flora of undoubted Jurassic age. A few fossil plants, including Upper Gondwana forms, associated with Umia forms, have been found in the Katrol stage, which is probably newer than the beds which have yielded the Upper Gondwana flora of the Peninsula.

THE CRETACEOUS SYSTEM

The Cretaceous system is represented on a very extensive scale by a varied assemblage of marine, fluviatile, and volcanic rocks both in the Peninsula and in the geosynclinal areas. In the geosynclinal regions it often attains a vast thickness, and both the Lower and Upper Cretaceous frequently assume the "flysch" facies of unfossiliferous, or nearly unfossiliferous calcareous sandstones and greenish arenaceous shales.

Flysch facies of Cretaceous.

Along the borders of the Peninsular area, the Upper Cretaceous enters largely into the constitution of the Coastal System, to which it contributes sediments deposited during the marine transgressions of that period, the remnants of which are scattered over the low-lying lands of many parts of the globe. The Cenomanian transgression seems to have reached further into the low-lying districts of the Indian Peninsula than any of the preceding or succeeding ones.

Upper Cretaceous in Coastal System.

The close of the Cretaceous coincided with volcanic eruptions on a gigantic scale including the basaltic accumulations constituting the "Deccan Trap" of the Peninsula, and a varied series of volcanic and intrusive rocks in the geosynclinal areas.

Volcanic manifestations during Upper Cretaceous.

The composition of the Cretaceous varies so much from place to place that it will be best to deal separately with the successive regions along the geosynclinal zone. In Balúchistán the system occupies an important position along the

Geosynclinal facies of the Cretaceous. Cretaceous of Balúchistán.

calcareous zone where it consists mostly of limestones and shales except where the flysch facies predominates and the prevailing rocks become dark-greenish sandstone, and arenaceous shales of the same colour.

Belemnite beds.

The Neocomian, in its most typical and most complete development, includes two divisions, a lower one known as the "Belemnite beds," and an upper one constituting the Parh limestones. The "Belemnite beds," in their most characteristic form, are dark shales crowded with belemnites amongst which one especially notices the flattened forms of the genus *Duvalia*.

Parh limestones.

The overlying Parh limestones consist of very distinctly and regularly bedded brilliantly white, purple-red, and purple porcellanoid limestones with an aggregate thickness that reaches sometimes 1,500 feet. They are sometimes associated with bright purple-red shales.

The Parh limestones constitute a very conspicuous member of the calcareous zone from Gadani, 25 miles north-west of Karachi, up to Kelat and Quetta. West of Quetta their outcrop is continued into the Thal Chotiali, Pishin and Zhob districts. Rocks of the same type re-appear in the Arakan Yoma and the Andaman Islands.

The Parh limestones are conformable to the Belemnite beds and they both together constitute a single geological stage unconformably related both to the underlying Jurassic whose latest beds are Callovian and the overlying Upper Cretaceous which does not contain any strata of earlier age than Campanian. The two sub-divisions of the Neocomian, Belemnite beds and Parh limestones, are often found in superposition, or else the state is represented solely by one or the other.

The Parh limestones often constitute a concentric ring of very steep ridges encircling the gigantic dome-shaped hills formed by the dome-like anticlines of the massive limestone of the Jurassic, the Belemnite shales forming an intermediate circular valley. This concentric disposition is very noticeable in an ordinary topographical map, while the clear red and white colours of the Parh limestones contrast curiously with the dark tinge of the huge limestone masses which they encircle.

Upper Cretaceous of Balúchistán.

The lowest division of the Upper Cretaceous in the calcareous zone of Balúchistán and Sind, in which latter province they are only developed in the Laki Range, is a group of limestones known as the Hemipneustes beds, of Campanian or Lower Maestrichtian age (Lower or Middle zone of the Aturian or Upper Senonian) containing echinoids of the genera *Hemipneustes, Pyrina, Clypeolampas, Noetlingia,* and ammonites belonging to *Pachydiscus* and other genera. Foraminifera of the genus *Orbitoides* are abundant, the lowest beds containing *O. media,* while at higher horizons there occur *O. Hollandi, O. socialis,* and *Omphalocyclus macropora.* The Hemipneustes beds are succeeded by shaly beds usually unfossiliferous, but containing a band scarcely six inches thick crowded with

The last ammonites.

ammonites belonging to the genera *Indoceras, Sphenodiscus, Pachydiscus, Sehlüteria, Baculites.* The commonest fossil is *Cardita subcom planata.* This is the newest ammonite zone yet observed in Northern India. The ammonite shales are followed by a great thickness of sandstones of flysch facies, often interbedded with volcanic material, known

The Pab sandstones.

as the Pab sandstones. Usually the Pab sandstones are very unfossiliferous except for some curious markings frequently observed on the upper bedding surfaces of the

shales and preserved as relief casts on the lower surfaces of bedding of the overlying sandstones. They belong to the class of structures that used to be known as the "flysch algæ" on the supposition that they were of vegetable origin, but have now been proved to represent tracks of animals such as shrimps or annelids. Nevertheless highly fossiliferous bands are occasionally associated with the Pab sandstones, especially in their upper zones, the commonest fossil being *Cardita Beaumonti*. The uppermost *Cardita Beaumonti* beds are probably of Danian age.

Pseudo-fucoids.

The Cardita Beaumonti beds.

The volcanic rocks associated with these uppermost cretaceous beds are the local representatives of the Deccan Trap of the Peninsula. Only, instead of consisting almost entirely of basic lavas, as in the case of the Deccan Trap, they consist largely of submarine tuffs, and contain numerous andesitic and ryholitic as well as basaltic rocks. Large masses of red jasper are often developed in the submarine tuffs. Detached rock-specimens of this substance resemble the red jaspers of the Dharwar and Kadapah systems, but the rock occurs in the tuff as large irregular lumps, not in stratified layers. The volcanic rocks often assume the character of a breccia half intrusive, half extrusive, in which the included blocks of all kinds and ages of sedimentary and crystalline rocks vary from the size of a small pebble to that of an entire hill mass. Singular appearances are thus produced both in Balúchistán and in the Himalaya, the best-known example of which is the great igneous mass containing the "exotic blocks" of Johar on the Tibetan Frontier. Similar rocks occur in the

Extra-Peninsular representatives of the Deccan Trap.

Exotic blocks of Johar.

Upper Indus valley in Ladakh, and in the Porali valley which traverses in Balúchistán, the province of Jhalawan and the State of Las Bela.

Gabbro, serpentine, chrome, jadeite.

These intrusions often pass into gabbros and chrome-bearing serpentines. Some of the largest masses of gabbro are those of the Zhob valley in Balúchistán. The same rocks are observed at many places along the Inner or Northern zone of the Himalaya, in Upper Burma, in the Arakan Yoma, and the Andaman Islands. Serpentinous rocks of this description occurring in the Kachin Hills of Upper Burma are occasionally intersected by veins of jadeite, such as those worked in the famous jade mines of Tawmaw which have lately been geologically examined by Dr. Bleeck (Rec. G. S. I., Vol. XXXVI, page 254—284).

Cretaceous of the Himalaya.

Along the Inner or Northern Zone of the Himalaya, the Neocomian and Upper Cretaceous both assume the flysch facies and pass upwards into the volcanic representatives of the Deccan Trap often represented by the singular breccia mentioned in the previous paragraphs.

The total thickness, including the volcanic rocks, varies from 1,500 to 3,000 feet.

Chikkim limestone.

A white fossiliferous limestone, some 150 to 500 feet thick, sometimes underlies the Upper Cretaceous flysch. It is known as the Chikkim limestone and probably corresponds with the Hemipneustes beds of Balúchistán of Campanian age.

Cretaceous of the Arakan Yoma and the Andaman Islands.

In the Arakan Yoma and its southern continuation, the Andaman archipelago, the Cretaceous includes the same stages as in Balúchistán with the same facies. The Parh limestones, the Upper Cretaceous flysch with the *Cardita Beaumonti*

beds, the tuffs, serpentines, jaspers and other volcanic rocks equivalent to the Deccan Trap, have all been identified.

East of the Irawaddi there are no marine representatives of the Cretaceous.

The Cretaceous in the Coastal System.

Lower Cretaceous of Kachh.

The lower marine strata of the Umia beds in Kachh which are partly of uppermost Jurassic age, but probably include also some lowermost Cretaceous strata, are succeeded by the Umia plant beds whose age is probably Barremian. These are succeeded by the Upper Umia marine beds with ammonites of Aptian (Lower Greensand) age. These beds are said to be immediately succeeded by the uppermost Cretaceous Deccan Trap.

Umia beds.

The Umia beds are the only marine representatives of the typical Lower Cretaceous strata so far known in the Coastal System.

Albian Stage.

The Albian or Gault entirely absent from the geosynclinal areas appears to be represented in the Coastal System only by the lowermost beds of the Utatur stage of the Coromandel Cretaceous.

The great Cenomanian transgression.

The Cenomanian feebly represented or absent from the geosynclinal zones exhibits, by its widespread development in the Peninsular area, a marked contrast with these fragmentary occurrences of the Lower Cretaceous formations. The great Cenomanian transgression has had far-reaching effects in the Peninsular area. In certain instances, principally in the Narbada basin, its marine representatives extend to a considerable distance inland, while in regions situated beyond the reach of the marine invasion, the marine strata pass into the estuarine and fluviatile deposits of the

rivers whose course was temporarily shortened by the encroachment of the sea-coast.

Bagh and Lameta beds.

In the Narbada valley the marine representatives of the Cenomanian are known as the Bagh beds. On the Coromandel Coast they constitute the greater portion of the Utatur division of the Cretaceous. The fluviatile representatives are known as the Lameta beds.

Cretaceous of the Coromandel Coast.

Near the east coast of Southern India, from Pondicherri to Trichinopoli, one observes a very full sequence of Upper Cretaceous beds. The beds are principally shales and sandstones with some calcareous bands full of well preserved fossils that have been described in great detail by Forbes, Stoliczka and Kossmat. As is usual with the Coastal System, the strata dip at low angles towards the coast. There are three principal divisions, the Utatur, Trichinopoli, and Ariyalur. The

Stratigraphy.

Utatur stage.

Utatur consisting of fine silts, calcareous shales, and sandy clays, of ochreous tints, sometimes with a coral limestone at the base, contains over 100 species of ammonites distributed in three zones: the Schloenbachia beds with *Schloenbachia inflata, Turrilites Bergeri, Hamites armatus;* the Acanthoceras beds with numerous species of *Acanthoceras* and with *Turrilites costatus;* and an upper zone with *Acanthoceras conciliatum,* and *Nautilus Huxleyanus.* These three divisions correspond respectively with the Gault, Cenomanian, and Turonian.

Trichinopoli stage.

The Trichinopoli beds of Lower Senonian age (with 27 species of ammonites), consisting of sands, clays and shingle beds intercalated with shell-limestones, largely used for ornamental purposes, include a lower division characterized by *Pachydiscus peramplus, Protocardium*

Hillanum, etc., and an upper division with *Placenticeras Tamulicum*, *Heteroceras indicum*, etc.

Ariyalur stage.

The Ariyalur, about 1,000 feet (300 metres) thick, consists chiefly of white sands and green argillaceous sands, and is mostly unfossiliferous, except towards its lower and upper limits, where there are calcareous grits and shales full of fossils. The band at the base is especially fossiliferous and contains more than 50 species of ammonites belonging to the genera *Pachydiscus*, *Baculites*, *Sphenodiscus*, *Desmoceras*, etc., and numerous lamellibranchiata and gastropods among which the Cypreidæ and Volutidæ are particularly well represented. The uppermost strata of the Ariyalur are known as the Niniyur beds, and contain the characteristic Danian species *Nautilus danicus*.

Niniyur beds.

Cretaceous Beds of the Lower Godavari.

In the neighbourhood of Rajamahendri at the head of the Godavari delta, the Upper Gondwanas are overlaid by a 50-foot thick band of sandstone, the uppermost part of which is calcareous and is crowded with *Turritella* and other shells, none of which have been identified. This band which perhaps corresponds with the Ariyalur beds is overlaid by 100 to 200 feet of basalt of the Deccan Trap formation, in the midst of which are intercalated some thin bands containing a mixture of freshwater and marine shells, amongst which *Physa Prinsepii*, *Cerithium Stoddardi*, and *Morgania fusiformis* are especially interesting as indicating an Upper Maestrichtian to Danian horizon. The basalt is uncomfortably overlaid by the Rajamahendri beds, probably of oligocene age.

Cretaceous Beds of the Shillong Plateau.

At certain places along the southern border of the Shillong plateau, for instance the road to Cherra Poonjee, the cretaceous is represented by sediments

recalling those of the Coromandel. Like them they represent coastal deposits deposited during a marine transgression along the southern border of the Shillong plateau which was then, as to-day, a land area.

Fossils have been recorded only on the road to Cherra Poonjee, principally at Tharia Ghat, and they are exclusively Upper Senonian forms very similar to those from the Ariyalur beds of the Coromandel Coast.

The Cretaceous beds are overlaid by a varied series of Middle Eocene beds with coal-seams, some of which have been erroneously referred to the cretaceous period.

The Deccan Trap.

The close of the Cretaceous was marked in India by the gigantic volcanic outburst that overwhelmed a large portion of the Peninsula with the vast accumulation of bedded basalts known as the Deccan Trap. The western part of the Peninsula north of latitude 16° is almost entirely occupied by this formation. It is also largely represented in the extra-Peninsular geosynclinal areas by lavas, tuffs, and intrusive masses which have already been mentioned when dealing with those areas.

Maestrichtian and Danian age of Deccan Trap established by associated fossils.

The geological age of the Deccan Trap is established by the marine and freshwater fossils which abound in some of the intercalated sediments both in the Peninsular and extra-Peninsular area. The rocks most usually associated with the volcanics in the extra-Peninsular area are the Pab sandstones including the *Cardita Beaumonti* beds of Upper Maestrichtian to Danian age. The eruption has already commenced at the time of deposition of the underlying ammonite beds with *Cardita subcomplanata*. The fauna of the *Cardita subcomplanata* beds is mostly marine, but also includes freshwater forms, the commonest of which is *Physa Prinsepii*, which is one of the most characteristic fossils

of the freshwater intertrappeans of the Peninsula and of the fluvio-marine intertrappeans of Rajamahendri near the head of the Godavari delta. The latter also contain, as above mentioned, *Cerithium Stoddardi* and *Morgania fusiformis*, both of which are common fossils of the Maestrichtian of Persia.

The above fossil evidence clearly establishes the age of the Deccan Trap as Upper Maestrichtian to Danian.

Constitution of the Deccan Trap.

In the Peninsula the Deccan Trap formation consists almost entirely of superposed beds of basalt, sometimes reaching an enormous thickness as in the neighbourhood of Bombay where they must be accumulated to nearly 10,000 feet. The beds have been much cut up by denudation but are otherwise usually undisturbed and remarkably horizontal. Occasionally they are more or less tilted by disturbances which affected them subsequently to the close of the volcanic era. For instance, there is a general gentle seaward dip at Bombay, while one also observes somewhat more abrupt disturbances along the westward continuation of the great boundary fault constituting the northern limit of the Satpura basin of Gondwanas, south of the Narbada, and also in the Rajpipla hills between the lower Narbada and lower Tapti. These disturbed areas are often those in which dykes are abundant and which correspond therefore with unstable fractured zones.

Elæolite-syenite of Girnar.

In addition to these linear fissure-dykes there are some massive intrusions in Kachh and Kathiawar. The great intrusive mass constituting Girnar hill in Kathiawar is lithologically different from the usual basaltic rocks of the system ; it has been studied by Dr. Evans who recognised that it consists of elæolite-syenite

Usually the bedded rocks and the fissure-dykes of the Deccan Trap are ordinary heavy augite basalts or dolerites in which olivine is rare or absent. Dacitic lava flows have been discovered by Mr. Fermor at Pawagarh hill in Gujrat.

Dacites of Pawagarh.

The Deccan Trap eruptions appear to have coincided with the final breaking-up of Gondwana-Land.

THE EOCENE SYSTEM.

If we represent on a map of India the various geological divisions so far described, we shall find that one of the three regional divisions of India, the Peninsula, has now been completed except for some strips of tertiary and quarternary beds along the sea-coast and along the valleys of some of the great rivers, and a few tertiary exposures in Gujrat, Kathiawar, and Western Rajputana. Of the remaining paragraphs, those concerned with the quarternary era will deal principally with the third of the great regional divisions, the Indo-Gangetic plain, while those concerned with tertiary rocks will deal principally with the great mountain ranges of extra-peninsular India.

With the end of the Cretaceous, the Mesozoic or secondary era came to a close. The gap between Cretaceous and Tertiary, due to a universal temporary regression of the ocean, is just as pronounced in India as in any other part of the world. Even in Sind where the oldest Tertiary of India is met with, both the uppermost Cretaceous and lowermost Tertiary are missing.

Stratigraphical break between Cretaceous and Tertiary.

The Eocene in India, as in other countries, includes the bulk of the nummulitic limestones. It includes three principal divisions: the Ranikot, the Laki, and the Khirthar. The Ranikot, restricted to a comparatively small area in the province of Sind, includes a lower division of fluviatile sandstones corresponding with the Woolwich and Reading beds, and an upper marine division contemporaneous with the London Clay. The uppermost beds of the Upper Ranikot contain the earliest abundant nummulites belonging principally to the species *N. planulatus*.

Ranikot series.

Laki series with coal-seams.

The Laki division exhibits either a shaly arenaceous or a calcareous facies according to various localities. Its characteristic nummulites are *N. atacicus* and *N.* (*Assilina*) *granulosa*. The Laki limestones abound also in foraminifera of the genus *Alveolina*. The Laki division is economically of great importance, containing as it does an important coal-bearing horizon in Balúchistán, in the Punjab, and in Assam.

Khirthar series.

The Khirthar consists largely of limestones which, in the range of that name along the Sind-Balúchistán frontier, are as much as 3,000 feet thick. It contains the zones richest in nummulites amongst which may be mentioned *N. lævigatus*, *N. perforatus*, *N. gizehensis*, *Assilina spira*.

The upper beds of the Khirthar limestone contain *N. complanatus*, the largest species of the genus. The Laki and Khirthar correspond with the Lutetian, that is, the Middle Eocene. The Bartonian (Upper Eocene) doubtfully present at the top of the Khirthar in the Mula Pass of Balúchistán is certainly absent from all other exposures, there being a widespread unconformity between the Khirthar and the following beds of Oligocene age.

Both the Laki and Khirthar are well developed in Kachh, in the Salt Range, in the Arakan Yoma and in the Andaman Islands. The Laki is largely developed in Western Rajputana. The nummulitics of Surat and of Assam and the Subathu group of the Simla region correspond with the Khirthar.

THE PEGU OR MEKRAN (FLYSCH) SYSTEM.

(*Oligocene and Lower Miocene.*)

THE end of the Eocene coincides with the opening of the last and most important chapter of the geological history of India. The quiescent conditions that had lasted ever since the Upper Carboniferous now came to an end, and the earth's crust entered into a renewed phase of disturbance. The enormous mass of sediments that had so quietly accumulated upon the gradually sinking floor of the Tethys was now powerfully compressed in a horizontal (tangential) direction, and was thrown into a succession of ridges, which became the great mountain ranges of the present day: the Alps, the Pyrenees, the Himalaya.

Upheaval of the Himalaya.

Three phases can be distinguished in this grand upheaval, one at the end of the Eocene, one in the Middle Miocene, and the last in the Middle or Upper Pliocene. The first upheaval, although it extensively folded the Eocene and underlying older strata, uplifting them in many regions into ranges of considerable altitude, was not nevertheless sufficient to obliterate the Tethys. This ocean still preserved its continuity; the gradual subsidence of its floor, of which we have evidence from Upper Carboniferous to Eocene, still continued or even became accentuated, judging by the enormous thickness of sandstones and gritty shales all bearing evidence of deposition in rather shallow water that accumulated throughout the Oligocene. These dark grey or greenish shales and often calcareous sandstones are singularly uniform and monotonous in appearance, constituting the bulk of the great formation known as the "flysch." Beds of similar appearance had already been deposited in the same area

The flysch.

during Eocene and even Cretaceous times, but it is during the Oligocene that most of the flysch was deposited.

Towards the end of the Middle Miocene, a second orogenic phase still more powerful than the Upper Eocene one upheaved the flysch strata, folding them into innumerable corrugations, and the Tethys was cut up into a series of disconnected lagoons or inland seas which finally disappeared in the last great upheaval of Pliocene times.

A homogeneous series of strata was thus formed resting unconformably upon the Eocene, and unconformably overlaid by the Upper Miocene and Pliocene. It constitutes the Pegu system of Burma, and the Mekran system of Balúchistán.

Kojak shales.

The flysch facies of this system in Balúchistán is known as the Kojak shales, an almost unfossiliferous formation, occasionally containing, however, fossiliferous bands with *Nummulites intermedius*, *N. vascus*, and other fossils of Oligocene age.

Calcareous zones of Sind and Balúchistán.

In the neighbourhood of what was once the shore of the ocean in which the flysch was deposited, the sediments acquire a calcareous facies and become highly fossiliferous. In Sind and in Balúchistán the fossiliferous facies is divided into three principal divisions, the Nari, Gaj, and Hinglaj. The Nari includes the Middle and part of the Upper Oligocene. Its lower division frequently consists of massive nummulitic limestones resting with varying amounts of unconformity on the nummulitic limestones of Eocene age. It is the last horizon rich in large nummulites, principally *N. intermedius* and *N. vascus*, accompanied by lepidocyclines of the group of *L. dilatata*. In the Upper Nari the foraminifera attain their highest develop-

Nari series.

ment, the Burmese species *L. Theobaldi* Carter being as much as seven inches in diameter. Other characteristic Nari fossils are *Montlivaltia Vignei, Breynia multituberculata, Eupatagus rostratus, Lucina columbella, Venus Aglauræ.*

Gaj series.

The Gaj consisting of shales and coral limestone is of uppermost Aquitanian age. Its leading fossils are *Lepidocyclina marginata, Breynia carinata, Eupatagus patellaris, Echinolampas Jacquemonti, Vicarya Verneuli.*

Hinglaj series.

The Hinglaj series, well developed along the Mekran Coast, in the Persian Gulf Islands, in the Irawaddi Valley and Andaman Islands, consists principally of clays and sandstones and conglomerates with a few calcareous bands. The characteristic foraminifera in Burma and the Andamans are *Nummulites Niasi* and *Amphistegina Niasi.* The Hinglaj series is mainly of Burdigalian age (Lower Miocene), the uppermost beds being perhaps Middle Miocene. These uppermost beds contain numerous large pectens, the commonest species being *P. Vasseli.*

Bugti Beds.

In the Bugti hills of Balúchistán the marine element in the Nari beds become extremely reduced, and is only represented by a small thickness of brown arenaceous limestones with the characteristic nummulites and lepidocyclines towards the base of the system. The overlying beds are fluviatile sandstones that have yielded a remarkable fauna of vertebrates of Aquitanian or Burdigalian age including *Anthracotherium* and other interesting forms. They also contain freshwater mollusca, especially ribbed species of *Unio*, such as *Unio cardita, U. Vicarya*, and *U. cardiiformis.*

These beds were for a long time confounded with the Lower Siwaliks which overlie them unconformably and are also fossiliferous. The stratigraphy and

palæontology of this interesting region have been unravelled by Mr. Pilgrim.

Granitic intrusions.

Corresponding in age with a portion of the Pegu system are the great intrusions of granite, of diorite of augite-syenite, and of porphyries, that cut through the Eocene rocks of Balúchistán forming some of the highset hill ranges, such as the Ras Koh, the Khwaja Amran. Of the same age are the Tertiary granites of the Northern Himalaya and of Tibet.

Petroleum, salt, and sulphur.

Other products of this igneous activity are the petroleum of Burma, Assam and the Punjab, and in all probability the salt-marl and salt deposits of the Salt Range, as well as many deposits of sulphur. The petroleum, owing to its inferior density as compared with water, has collected along the axes of anticlines in the Pegu system, wherever a layer of argillaceous rock has provided an impermeable roof. Gases have also collected along these anticlinal crests, and are apt to find their way to the surface through fissures, producing the mud-volcanoes that often rise along the outcrops of these anticlinal arches. There are four principal groups of mud-volcanoes, situated respectively along the Eastern and Western borders of the Arakan Yoma, in the Gomal Valley along the Afghan-Báluch Frontier, and along the Mekran Coast.

Mud-volcanoes.

Murree beds.

In the Punjab, the equivalents of the Pegu system are known as the Murree beds; in the Himalaya as the Kasauli and Dagshai.

Cuddalore sandstones.

The Cuddalore sandstones of the east coast of the Peninsula probably belong to this system.

THE SIWALIK SYSTEM.

In India, there are no typical marine deposits other than pleistocene "raised-beaches" newer than the uppermost beds of the Pegu system. The main upheaval of the Himalaya and of the mountains of Balúchistán and Burma took place during the Middle Miocene, after which nothing remained of the ocean that formerly occupied their site but a number of basins isolated from one another in which the strata known as Siwaliks (equivalent to the Manchhar beds of Sind, Irrawaddi beds of Burma, and Gobi beds of Central Asia), principally clays, sandstones and conglomerate were deposited. Like all inland seas, these basins were subjected to variations in their degree of saltness that were prejudicial to the development of aquatic organisms. Hence the remains of animals of this class are scanty. Some of the conglomerate beds, especially in the Upper Siwaliks, are of fluviatile origin, and may be regarded as alluvial fans.

The great thickness of the Siwalik formation, especially at the foot of the Himalaya, indicates a gradual deepening of the furrows in which they were deposited, somewhat analogous to the gradual subsidence indicated by the enormous thickness of the flysch.

In Pliocene times, these beds were upheaved during the final phase of mountain-growth of the Himalaya, after which the only earth-movement that has taken place is a comparatively gentle warping that has affected certain regions of Peninsular and extra-Peninsular India and of the Indo-Gangetic plain in Post-Pliocene times. In the Himalaya, the final upheaval was sufficiently violent to thrust the older rocks over the newer ones in a north to south direction, producing the structures known as thrust-planes. The structural

peculiarities of the Outer Himalaya and sub-Himalayan ranges have been elucidated principally in the works of Medlicott and of Middlemiss

The chief interest of the Siwalik formation resides in the remains of extinct animals that have been made known to the scientific world through the researches of Cautley, Falconer, and Lydekker The bones and teeth of these animals are found principally in the conglomeratic layers at the base and at the top of the series. Those found at the base are of Upper Miocene (Pontian) age, and contain a fauna contemporaneous with that of Pikermi in Greece. Amongst the numerous extinct genera of this fauna may be mentioned *Dinotherium*, *Mastodon*, *Hipparion*, *Helladotherium*, *Hyænarctos*. The upper conglomerates are of Pliocene age and contain the living genera *Elephas*, *Equus*, *Ursus* and many others, all of them represented, however, by extinct species.

Siwalik fauna.

Owing to the abundance of silicified tree-trunks, the Siwaliks are sometimes spoken of as the "fossil-wood-group."

Fossil wood.

The Siwaliks constitute the southern fringe of the Himalaya, and are largely developed in the Punjab, in Balúchistán, in Assam, and in Burma.

THE QUATERNARY ERA.

IT IS during the final Pliocene uplift that the Himalaya and many of the most important ranges of the globe attained their maximum height. Since then denudation has gradually lowered their altitude. The growth of these numerous mountains caused a remarkable change in the climatic conditions of the globe, and contributed to the extensive glaciation that has received the name of Glacial Period.

Glacial Period.

The continental ice-sheets of high latitudes and the mountain glaciers advanced and retreated several times during the Glacial Period, these oscillations coinciding to a large extent with alternately moist and arid periods. The traces left by these changes of the degree of humidity constitute the principal record of the Glacial Period in countries nearer the Equator.

The ultimate fate of all large continental areas has been the definite establishment of arid and desertic conditions through the gradual desiccation and filling up of the inland basins that still subsisted after the final Pliocene upheaval.

Gradual desiccation of the Asiatic continent.

Indications of the Glacial Period in the mountains of India have not been clearly recorded, the question having scarcely received any attention.

Former greater extension of Himalayan glaciers.

The Himalayan glaciers were far more extensive during the Glacial Period than at the present day, though they still include some of the largest glaciers of the globe. According to R. D. Oldham's investigations, there are indications of three great oscillations of the extension of the glaciers coinciding with some of the "glacials and interglacials" of the great ice-age in Europe. There are distinct indications, moreover, of the rapid

desiccation, since the termination of the Glacial Epoch of the countries forming the north-west portion of the Empire. This desiccation has become aggravated to a marked degree even during the historical period

It is not certain whether at the end of the Pliocene upheaval an arm of the sea still separated the Himalaya from the Indian Peninsula, but if this were so, it soon became filled by the products of the disintegration of the Himalaya, and in this manner originated the great alluvial plain of the Ganges, which now links the Peninsula together with the Asiatic continent. The great depth of the Ganges alluvium, as revealed by borings, indicates that in its case also subsidence must have proceeded simultaneously with deposition.

Formation of the Ganges alluvium.

Except in the neighbourhood of the delta, the greater portion of the alluvial plain is above the level of the highest floods of the Ganges and its tributaries, indicating that this area has been upheaved, or that the delta region has been depressed within relatively recent times. The presence of a mass of ancient alluvium, known as the Madhupur jungle north of Dacca in the midst of the delta region, further indicates that a certain amount of disturbance must have occurred. The existence of ancient alluvial areas enclosed within rock basins along the course of some of the Peninsular rivers, such as the Narbada, Tapti and Godavari, points to the same conclusion, and it is evident that a certain amount of irregular warping has affected India in Pleistocene times. In consequence of these physical changes, the ancient alluvium and the one still in process of formation can be readily distinguished from one another. They are known in the vernacular as "bhángar" and "khádar." In geological age, they correspond with the two main divisions of the Quaternary era, the Pleistocene and Recent. The

Older and Newer alluvium.

Pleistocene age of the bhángar or older alluvium is clearly shown by the remains of numerous extinct animals, amongst which may be mentioned *Elephas antiquus*, a characteristic species of the Pleistocene of Europe, and various extinct species of horse, ox, rhinoceros, hippopotamus. Contemporaneous with these are the earliest remains of prehistoric man in the shape of stone implements belonging to the "Chellean" or amygdaloid type, the earliest type of the earlier stone age.

Prehistoric man.

Implements of the amygdaloid type have been found embedded in "laterite," a ferruginous material, which is formed as a superficial alteration of rocks in regions subjected to "monsoon" conditions, that is, to alternately wet and dry seasons. The effect of lateritic weathering is to remove the silica of rocks, leaving a concretionary mass consisting of hydrates of iron, aluminium or manganese. The silica is redeposited over large areas as a jaspery layer often pseudomorphous after the rocks which it gradually replaces. These siliceous replacement rocks are often observed in the neighbourhood of extensive spreads of laterite.

Laterite.

When the laterite is very free from silica and contains locally a large excess of the hydrates either of iron, aluminium or manganese, it constitutes valuable ores of these metals.

The laterite is largely of Pleistocene age, but some of it may still be forming at the present day, while there are important masses of the same material that were formed in Eocene or even earlier times. It has already been mentioned that stratigraphical breaks are often disclosed by a layer of laterite, indicating an interval of continental conditions.

Some of the "raised beaches" observed all round the coasts of India at altitudes of as much as 100 feet are probably

Raised beaches.

Pleistocene. The consolidated wind-blown calcareous sand largely made up of foraminiferal tests, which occurs along the coasts of the Arabian Sea and is largely used as a building material under the name of Porbandar stone, is also probably Pleistocene.

Porbandar stone.

There are two regions of Pleistocene and Recent volcanic activity situated along lines of dislocation in the curved system of ranges on either side of the great Himalayan "arc." The eastern one situated in the "Malay arc" follows the inner or eastern side of the Arakan Yoma and its continuation the Andaman Islands, the best known volcanoes being Pupa, Narcondam Island, and Barren Island.

Recent volcanoes.

The latter situated furthest from the Himalaya is the newest and only active cone of the series.

Along the western or "Iranian arc," the largest volcano within the Indian Empire is the extinct Koh-i-Sultán, in the Nushki Desert.

Here also the cones become newer as one recedes from the neighbourhood of the Himalaya: west of the Koh-i-Sultán, the Koh-i-Taftán situated in Persia, is still active. All the above-mentioned volcanoes are andesitic.

Oscillations of the relative sea-level during the Recent Period are indicated by such features as low-level raised beaches, the oyster-bed lately discovered in Calcutta, the submerged forests of Bombay and the East Coast.

Numerous minor changes due to marine denudation, to fluvial sedimentation, to alterations in the course of rivers, earthquakes, landslips, the growth of deltas, cyclones, and other actual causes have been observed during the historical period.

IN ACTIVE PREPARATION

THE GEOLOGY OF INDIA

BY

ERNEST VREDENBURG

Table of Geological Formations in the Indian Empire.

Peninsular Area.	Kachh.	Salt Range.	Himalayan Region and N.-W. Frontier.	Baluchistan and Sind.	Burma and Malay Region.	Geological age.
					Volcanoes of Burma, the Bay of Bengal, Baluchistán.	
Newer alluvium (khádar), delta formations, etc.						RECENT.
Karnúl caves.						
Older alluvium (bhángar) of Ganges, Narbada, Godávari, etc., with *Elephas antiquus*, *Hippopotamus*, etc., and Chellean implements; older raised beaches, Porbander stone, etc., etc.						PLEISTOCENE.
FINAL PHASE OF HIMALAYAN UPHEAVAL.						
						PLIOCENE.
SIWALIK. Upper beds with *Equus*, *Elephas*, *Ursus*, *Sivatherium*, etc.						
SIWALIK. Middle series.						
SIWALIK. Lower beds with *Hipparion*, *Mastodon*, *Dinotherium*, *Helladotherium*, etc.						PONTIAN.
SECOND PHASE OF HIMALAYAN UPHEAVAL.						
PEGU or MEKRAN SYSTEM. Upper beds of the Coastal System, including the marine beds below the laterite of Bengal, the Rajamahendri beds, the Cuddalore sandstones, the Orbiculina beds of Qilon and the Gáj beds of Kathiawar.	PEGU or MEKRAN SYSTEM. Hingláj or Dwarka series. Gáj series. NARI: Upper. Lower.	Murree beds, Intrusive salt and petroleum.	Kasauli, Dagshai, and Murree beds. Intrusive granites.	Flysch System. Intrusive Granites, Syenites, etc. Hingláj series. Gáj series. NARI: Upper. Lower. Khirthar beds.	PEGU SYSTEM. Intrusive petroleum.	VINDOBONIAN.
						BURDIGALIAN.
						AQUITANIAN.
						STAMPIAN.
						SANNOISIAN.
FIRST PHASE OF HIMALAYAN UPHEAVAL.						BARTONIAN.
KHIRTHAR. Nummulitics of Broach, Sonni, etc.	Khirthar series.	Khirthar series.	Nummulitics of Subáthu.	Khirthar series.	Khirthar series.	LUTETIAN.
LAKI. (Coal-measures.) Nummulitics of Western Rajputana (part.)	Laki series.	Laki series.	Laki series.	Laki series. Zone of *N. planulatus*. Lower marine beds. Fluviatile beds. RANIKOT (Sind only).	Laki series.	CUISIAN.
						LONDON CLAY.
						WOOLWICH AND READING.

Peninsular Area.	Kachh.	Salt Range.	Himalayan Region.	Baluchistan and Sind.	Burma.	Geological Age.
DECCAN TRAP. NINIYUR.	DECCAN TRAP.	"*Cardita Beaumonti*" beds.	Breccia of Johar, volcanics of Upper Indus.	Deccan Trap, intrusive gabbros and serpentines. Pab sandstones. *Inoceras* beds.	Intrusive serpentines.	DANIAN. MAESTRICHTIAN.
ARIYALUR { Tharia beds of Assam.				*Hemipneustes* beds.		CAMPANIAN.
TRICHINOPOLI. { Upper. Lower.						LOWER SENONIAN.
UTATUR. { Upper Utatúr. *Acanthoceras* beds of Southern India, Bégh and Lameta beds. *Schloenbachia* beds of Southern India.			Chikkim series of Central Himalaya, *Acanthoceras* beds of Hazara and Samana.			TURONIAN. CENOMANIAN. GAULT.
	Upper UMIA beds.			Farh limestone		LOWER GREENSAND.
	Plant beds.	Belemnite beds.	Giumal sandstone.	Belemnite shales.		WEALD.
UPPER GONDWANA. TRIPETTY, CHIKIALA, etc. { Fossiliferous beds of Western Rajputana.	Lower UMIA beds.	Fossiliferous limestones.	SPITI SHALES. { Lochambel beds. Chidamu beds.			PORTLANDIAN. KIMMERIDGE.
	KATROL.		*Belemnites Gerardi* beds.			SEQUANIAN.
	CHARI.		*Sulcacutus* beds,	*Polyphemus* beds.		OXFORDIAN. CALLOVIAN.
	PATCHAM.		Massive limestone.	Massive limestone.		BATHONIAN. BAJOCIAN.
VEMAVARAM, JABALPUR, KOTA, etc., RAJMAHAL.			*Spiriger Nori-*	Black limestones.		LIAS.
MALERI. KAMTHI. PANCHIRI.		Limestone with bivalves. Ceratite beds.	Kiogarh blocks. *Megalodon* limestone. Monotis shales. Juvavites and Halorites beds. Tropites beds. Halobia beds. Daonella beds. Muschelkalk. Hedenstroemia, Ophiceras and Otoceras beds.	Monotis shales.	Rhætic of Shan States.	RHÆTIC. NORIAN. CARNIAN. MUSCHELKALK. BUNTER.

CORRESPONDING BEDS NOT CLASSIFIED.

	Peninsular Area.	Salt Range.	Himalayan Region and N.-W. Frontier.	Baluchistan and Sind.	Burma and Malay Region.	Geological age.
Lower Gondwana.	Damuda. Raniganj. Ironstone shales. Barákar.	Upper Productus beds.	Productus shales.			Zechstein.
		Kálabágh beds.	Chitichun.			Rothliegende.
		Virgal beds.	Fenestella shales, Zewan beds.			
	Talchir. Karharbári. Boulder-bed.	Katta and Amb beds.	Plant-beds of Kashmir.	Fusulina limestones.	Fusulina and Schwagerina limestones.	Artinsk.
		Speckled sandstone and Boulder-bed.	Po series.			Uralian.
			Plant-beds of Spiti.			Moscovian. (English coal-measures.)
			Volcanics of Kashmir. Lipak series.			Lower Carboniferous.
			Fossiliferous beds of Chitrál.		Wetwin shales.	Devonian.
			Muth quartzite.		Padaukpin limestone.	
			Upper and Lower Silurian fossiliferous beds.		Zebingyi beds, Namhsin sandstones.	Upper Silurian.
					Fossiliferous beds.	Lower Silurian.
Vindhyan.	Upper Bhander.	Magnesian sandstone.	Upper Haimanta.			Upper Cambrian.
	Lower Bhander.	Neobolus beds.	Deoban and Krol series.			Middle Cambrian.
	Kaimur & Rewa.	Purple sandstone.				
			Lower Haimanta.		Pre-Silurian Sandstones, etc.	Lower Cambrian.
	Lower Vindhyans including Karnúl and Maláni beds. Jalor and Siwana granites.		Baxa, Blaini and Attock series.			? Pre-Cambrian.
Cuddapah.	Upper, including Nállamalai, Kistna, Kaládgi series.					Algonkian.
	Lower. Bijawar, with Cheysir and Gwálior series, and basic volcanic rocks.					
	Papaghni.					
	Dharwar, (Champáner, Chilpi, Karakpur series, etc.) Dome-gneiss, mica-pegmatites, etc.		Daling, Jaunsar, Vaikrita series, etc.		Crystalline limestones, etc.	Huronian.
	Beewada Gneiss.					
	Nilgiri or Mountain Gneiss, granitic or granulitic in structure and rich in enstatite, also Anorthosites.					Archæan.
	Bundelkhand Gneiss, including granitoid gneisses such as the Bala Ghat or Hosur Gneiss.		Central Gneiss.		Fundamental Gneiss.	
	Bengal Gneiss, including the schistose and banded gneisses.					